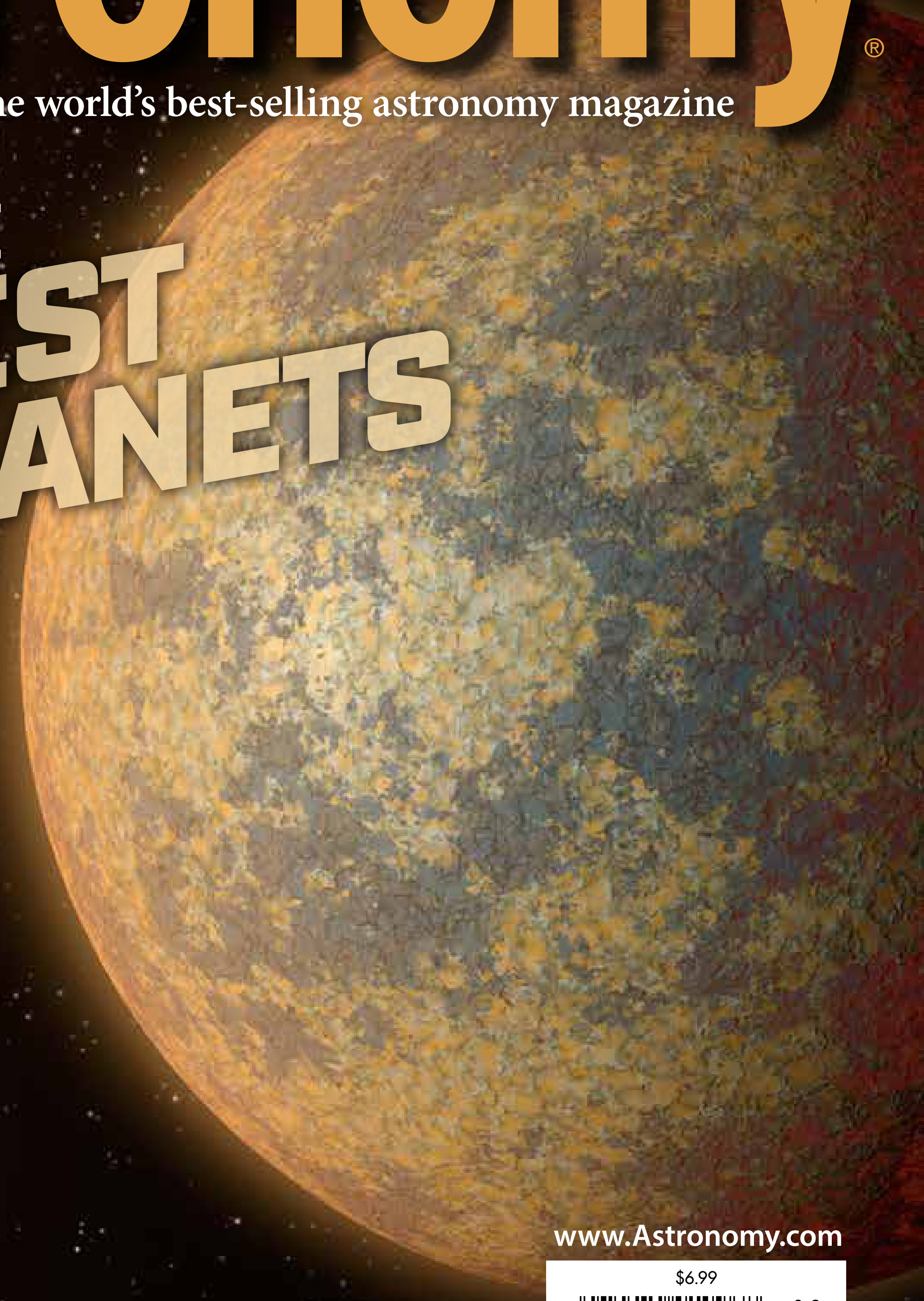
Catch this month's dazzling meteor show p. 52

AUGUST 2021

Astronomy®

The world's best-selling astronomy magazine



NEW RESEARCH

HUNTING THE NEAREST EXOPLANETS

TESS is revolutionizing our understanding of planets in our galaxy p. 14

Observe JUPITER at its best

p. 40

www.Astronomy.com

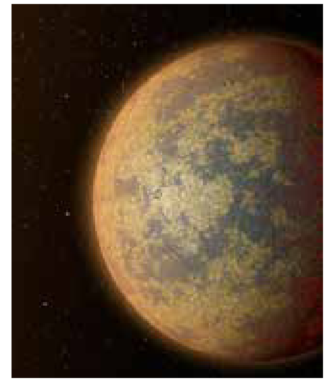
$6.99

Vol. 49 • Issue 8

AND MORE

CONTENTS

AUGUST 2021
VOL. 49, NO. 8



ON THE COVER
Astronomers are discovering more and more exoplanets, such as YZ Ceti c, which lies only 12 light-years from Earth. NASA

FEATURES

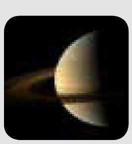
COLUMNS

IN EVERY ISSUE

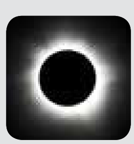
»

ONLINE FAVORITES

Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.



News
The latest updates from the science and the hobby.



Trips and Tours
Travel the world with the staff of *Astronomy.*

Sky This Week
A daily digest of celestial events.

Ask Astro Archives
Answers to all your cosmic questions.

Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Media Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, PO Box 8520, Big Sandy, TX 75755. Canada Publication Mail Agreement #40010760.

The exoplanet explosion

Astronomers have found an increasing number of possibly habitable worlds, including Kepler 62f, which has a mass 35 times that of Earth.
NASA/AMES/JPL-CALTECH

In 1992, a discovery rocked the astronomy world when astronomers found a planet orbiting a pulsar in the Milky Way Galaxy. It was the first planet discovered outside our own solar system. Technology and emerging, clever techniques were on parallel tracks to give us immense new insight into the galaxy around us. Thirty years after the initial discovery, we now know of more than 4,700 extrasolar planets in nearly 3,500 different systems.

None of this is really surprising. The conventional wisdom about how stars form suggests that a disk of debris — of planets and small bodies like asteroids and comets — should be commonplace, if not universal. It is comforting to know that thousands of stars relatively near us in the Milky Way have their own planetary systems. However, despite the exaggerations of the many press releases of past months and years, we have not found "another Earth" as yet. But the searches continue at an accelerating pace. The business of exoplanet discovery is now a full-on cottage industry of its own.

The workhorse instrument in the search has been the Kepler Space Telescope, which launched in 2009 and operated until 2018. Astronomers used Kepler to detect many hundreds of exoplanets, despite the fact that its primary search area was limited to a 100° square of sky toward the constellations Cygnus and Lyra.

Kepler's successor, if you will, the Transiting Exoplanet Survey Satellite (TESS), was launched in 2018 and has already detected more than 2,600 exoplanet candidates. Its search area is about 400 times larger than that of Kepler, and it focuses on surveying the brightest stars near Earth.

In this issue, MIT's George Ricker, the principal investigator of TESS, describes the science behind the mission and its exciting discoveries to date (page 14). This behind-the-scenes look by the mission's leader will give you the most current glimpse of the state of exoplanet research and the many exciting paths it will take over the coming days and years.

Yours truly,

David J. Eicher

Follow the Dave's Universe blog: **www.Astronomy.com/davesuniverse**
Follow Dave Eicher on Twitter: **@deicherstar**

FOLLOW *ASTRONOMY*

facebook.com/AstronomyMagazine
twitter.com/AstronomyMag
youtube.com/user/AstronomyMagazine
instagram.com/astronomy.magazine

Astronomy

Editor David J. Eicher
Design Director LuAnn Williams Belter

EDITORIAL
Senior Editor Mark Zastrow
Production Editor Elisa R. Neckar
Senior Associate Editor Alison Klesman
Associate Editor Jake Parks
Associate Editor Caitlyn Buongiorno
Editorial Assistant Hailey McLaughlin

ART
Illustrator Roen Kelly
Production Specialist Jodi Jeranek

CONTRIBUTING EDITORS
Michael E. Bakich, Bob Berman, Adam Block, Glenn F. Chaple Jr., Martin George, Tony Hallas, Phil Harrington, Korey Haynes, Jeff Hester, Alister Ling, Stephen James O'Meara, Martin Ratcliffe, Raymond Shubinski, Richard Talcott

EDITORIAL ADVISORY BOARD
Buzz Aldrin, Marcia Bartusiak, Jim Bell, Timothy Ferris, Alex Filippenko, Adam Frank, John S. Gallagher III, Daniel W. E. Green, William K. Hartmann, Paul Hodge, Edward Kolb, Stephen P. Maran, Brian May, S. Alan Stern, James Trefil

Kalmbach Media
Chief Executive Officer Dan Hickey
Senior Vice President, Finance Christine Metcalf
Senior Vice President, Consumer Marketing Nicole McGuire
Vice President, Content Stephen C. George
Vice President, Operations Brian J. Schmidt
Vice President, Human Resources Sarah A. Horner
Advertising Sales Director Scott Redmond
Circulation Director Liz Runyon
Director of Digital Strategy Angela Cotey
Director of Design & Production Michael Soliday
Retention Manager Kathy Steele
Single Copy Specialist Kim Redmond

ADVERTISING DEPARTMENT
Phone (888) 558-1544
Ad Production AdServices@Kalmbach.com
Dina Johnston, djohnston@kalmbach.com

RETAIL TRADE ORDERS AND INQUIRIES
Selling *Astronomy* magazine or products in your store:
Phone (800) 558-1544
Outside U.S. and Canada (262) 796-8776, ext. 818
Fax (262) 798-6592
Email tss@kalmbach.com
Website www.Retailers.Kalmbach.com

CUSTOMER SALES AND SERVICE
Phone (877) 246-4835
Outside U.S. and Canada (903) 636-1125
Customer Service customerservice@AstronomyMagazine.info

CONTACT US
Ad Sales adsales@astronomy.com
Ask Astro askastro@astronomy.com
Books books@astronomy.com
Letters letters@astronomy.com
Products products@astronomy.com
Reader Gallery readergallery@astronomy.com
Editorial Phone (262) 796-8776

For reprints, licensing, and permissions:
PARS International at www.parsintl.com


Rogue planets traverse space alone.
NASA, JPL-CALTECH

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to ***letters@astronomy.com****. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Another sky

While reading Randall Hyman's excellent article, "The galaxy's marvelous rogues and misfits," from the April 2021 issue, I couldn't help but think about what the night sky would look like from a planet of a rogue star that is drifting somewhere between the Milky Way and Andromeda galaxies. I bet a night sky without stars would be very unsettling, at least for an earthling's perspective! — **Joe Stevens,** Casco, MI

A natural curiosity

David Eicher's February 2021 editorial, titled "A renewal for stargazing," couldn't have been more timely and spot-on. The two significant "once-in-a-lifetime" cosmic events in 2020, witnessed by so many, were definitely impressive enough to add new hobbyists to the ranks.

The universe is unraveling its never-ending mysteries in so many ways. It only shows humans will never get tired or bored as long as we have any semblance of curiosity. — **Raj Ramaswamy,** Novi, MI

A decade of change

Please accept my sincere thank you for the January 2021 special issue. The articles were all well done and help give perspective to the universe, beginning to end, as we know it. This issue is one I will keep as a reference. As a longtime subscriber, I would encourage you to create an issue in January 2031, a decade from now, to document how much the sciences advance our understanding of the universe. — **Larry Mortensen,** Rochester, MN

Correction

Our readers pointed out a mistake in "Planet captured in the light of a dying star" in the Quantum Gravity section of our February 2021 issue. The text incorrectly stated that the white dwarf was 40 percent the diameter of Earth. WD 1856+534 is actually 140 percent the diameter of our planet.

SNAPSHOT

NEW LIGHT ON THE VEIL NEBULA

Researchers are bringing out the fine details of this famous supernova remnant.

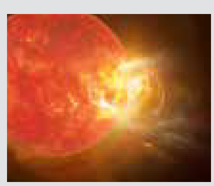
Around 8,000 years ago, our distant ancestors may have thought they were seeing a new star briefly join the northern sky. They were actually witnessing the explosive death of a massive star 2,000 light-years away in the constellation Cygnus. The shock waves from this supernova are still traveling away from the epicenter of the blast, colliding with the surrounding gas. These collisions create the appearance of delicate threads and filaments for which the remnant is famous, earning it the nickname Veil Nebula.

Only a portion of the nebula appears in this image. At 110 light-years in diameter, the remnant is so large that its various arcs each have their own designation. Named Caldwell 35 (NGC 6960), this portion is roughly 2 light-years across.

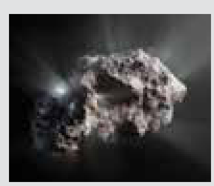
Using new processing techniques, astronomers have enhanced certain details of the nebula, such as features of doubly ionized oxygen (blue) and ionized nitrogen (red). While viewers can't spot the remnant with their naked eyes, it is visible through a telescope or binoculars under dark skies.

—CAITLYN BUONGIORNO

HOT BYTES



RECORD FLASH
A 2019 flare from the red dwarf Proxima Centauri — our closest stellar neighbor — was 100 times more powerful than any flare observed from the Sun, according to data from five telescopes. Such events give astronomers insight into whether planets around red dwarfs could be habitable.



FRESH POWDER
2I/Borisov, the first known comet from another star, is one of the most pristine comets ever observed. New analysis of data from its flyby of the Sun in 2019 found little sign of contamination from stellar winds or radiation, suggesting it left its host system without ever making a close pass to its star.

SIGNING OFF
Michael Collins, Command Module Pilot of Apollo 11, died April 28 at the age of 90. The astronaut helmed the Command Module *Columbia* solo for 14 orbits around the Moon as Neil Armstrong and Buzz Aldrin walked on the lunar surface July 20–21, 1969.

ESA/HUBBLE & NASA, Z. LEVAY. BOTTOM FROM LEFT: S. DAGNELLO, NRAO/AUI/NSF; ESO/M. KORNMESSER; NASA

A BIRD'S-EYE VIEW OF MARS

Ingenuity takes its fifth flight while Perseverance prepares for its main mission.

LEARNING TO FLY. During Ingenuity's third flight on April 25, the Perseverance rover captured this image of the hovering helicopter with one of its navigation cameras. NASA/JPL-CALTECH

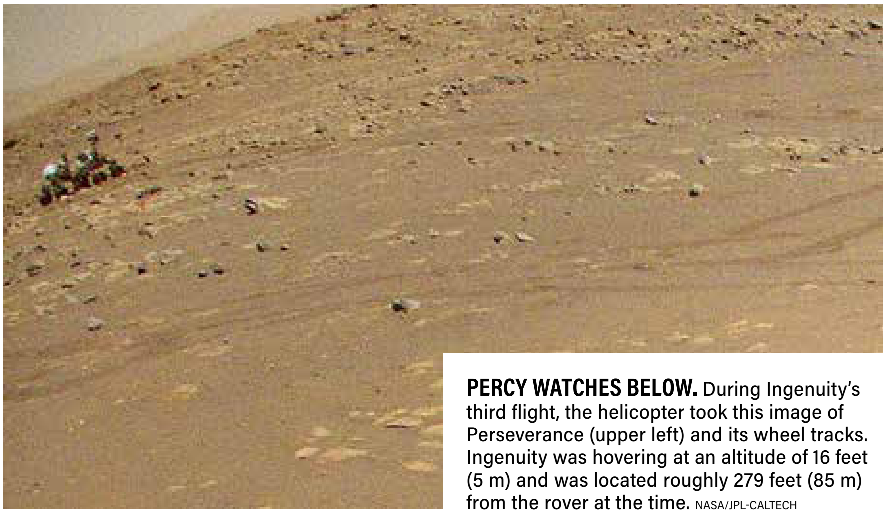
» It's been mere months since NASA's latest Mars rover, Perseverance, dramatically landed on the Red Planet's surface. And boy, has it been busy. Since touching down Feb. 18, Perseverance has tested its systems, recorded audio of its surroundings, captured thousands of images, spotted several possible science targets, and even proved it can pluck oxygen out of Mars' thin air — an invaluable option, should humans ever venture there.

Yet, if we're being honest, the car-sized rover has so far been overshadowed by a tiny, 4-pound (1.8 kilograms) helicopter that simply hitched a ride to the Red Planet to test out some new tech. That high-flying show stealer is none other than Ingenuity.

Ingenuity was born as an experimental tagalong mission slated for a 30-day run shortly after Perseverance's landing. After a slight delay, on April 19, Ingenuity successfully climbed to an altitude of 10 feet (3 meters) above Mars' surface, where it maintained a stable hover for 30 seconds. That's an impressive feat, considering the Red Planet's atmosphere is only 1 percent as dense as Earth's. What's more, that flight cemented Ingenuity as the first self-propelled aircraft to ever fly on another world.

"We don't know exactly where Ingenuity will lead us," said acting NASA Administrator Steve Jurczyk at a press conference after the maiden flight, "but today's results indicate the sky — at least on Mars — may not be the limit."

Within three weeks, Ingenuity logged a total of five flights. Its second (April 22) flew higher for longer and included sideways movement. The third (April 25) saw Ingenuity zip 164 feet (50 m) downrange, reaching a top speed of 4.5 mph (7.2 km/h) — some 450 times faster than Perseverance's top speed. During its fourth flight (April 30), it pushed the boundaries even further, making a longer round trip that also scouted new potential



PERCY WATCHES BELOW. During Ingenuity's third flight, the helicopter took this image of Perseverance (upper left) and its wheel tracks. Ingenuity was hovering at an altitude of 16 feet (5 m) and was located roughly 279 feet (85 m) from the rover at the time. NASA/JPL-CALTECH

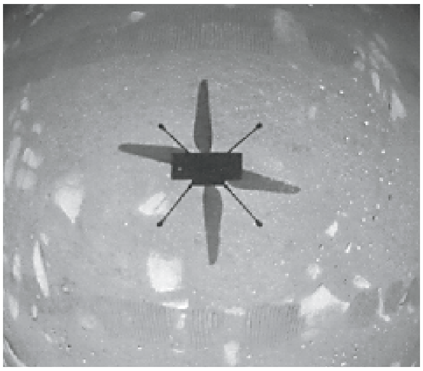
landing sites. And based on what it saw, Ingenuity's fifth flight (May 7) served as the craft's first one-way trip, traveling 423 feet (129 m) in 108 seconds to forever leave behind the Red Planet's first airfield.

Next, Ingenuity's team plans to push the craft's limits even further, as well as explore what the nearby environment has to offer. At the same time, Perseverance's team is kicking off the rover's mission in earnest. Percy is currently plodding south to the region where it will begin its scientific and sample collection efforts. Fortunately for Ingenuity, the rover's slow, methodical pace means it can continue acting as a communications relay to the helicopter, at least in the short term.

"The plan forward is to fly Ingenuity in a manner that does not reduce the pace of Perseverance science operations," said Ingenuity's chief engineer, Bob Balaram. "We may get a couple more flights in over the next few weeks, and then the agency will evaluate how we're doing. We have already been able to gather all the flight performance data that we originally came here to collect. Now, this new operations demo gives us an opportunity to further expand our knowledge of flying machines on other planets."

A tweet from May 11 on the rover's Twitter account shows Perseverance is ready to go, too: "The time has come: I'm switching from on-scene photographer to science investigator. Did this ancient lakebed ever have life? The tools I brought will help begin the hunt. I'm a bot on a mission." — JAKE PARKS

DELIVERY DROP-OFF. Ingenuity has its legs deployed in this photo, ready to drop from the belly of Perseverance, where it stowed away during its journey to Mars. NASA/JPL-CALTECH/MSSS



SHADOW SELFIE. Ingenuity snapped this shot of its own shadow while hovering on April 19, as it became the first powered craft to successfully fly on another world. NASA/JPL-CALTECH

QUICK TAKES

REUSABLE RIDE

SpaceX's Crew-2 launch on April 24 ferried four astronauts — two American, one European, and one Japanese — to the International Space Station (ISS). It was the company's third crewed flight and the first to reuse a rocket and crew capsule that had flown before.

LIGHT FINDS A WAY

Recent data from the Atacama Large Millimeter/submillimeter Array show baby stars being born less than 1,000 light-years from the Milky Way's center. Scientists had thought star formation was extremely difficult in the galaxy's central zone due to turbulence and strong magnetic fields.

SMATTERING OF ANTISTARS?

Astronomers have identified 14 stars that could be made of antimatter, based on their gamma-ray emissions, which resembles predictions of matter-antimatter annihilation. Although standard cosmology holds that nearly no antimatter remains in the universe, an experiment mounted to the ISS potentially detected antihelium in 2018 — which, if confirmed, could be stray antimatter from antistars.

OUT OF CONTROL

China successfully launched the first module of its Tiangong space station April 28. The Long March 5B rocket booster remained in orbit until making an uncontrolled reentry near the Maldives on May 9, prompting NASA administrator Bill Nelson to criticize China for "failing to meet responsible standards regarding their space debris."

GENDER GAP

If current trends continue, the percentage of women in Australia's astronomy workforce will not break 30 percent until 2080, according to a study published April 19 in *Nature Astronomy*. The authors recommend retention and hiring targets to bring that timeline forward. — MARK ZASTROW

Unusual records

You've got questions, we've got answers.

Potentially winning the prize for the easiest discovery ever, Supernova 1987A (indicated with an arrow on this photo) appeared as a new naked-eye star in the Large Magellanic Cloud. NASA/AMES RESEARCH CENTER

First-time celestial events and superlatives are always fun. So this month, let's scour the history books to uncover some record-holders you'll recognize — and some you won't.

Since astrophysicists spend 75 percent of their time doing spectroscopy, ***who first analyzed light from a distant object using a spectroscope?*** The answer is Robert Bunsen, whose super-hot burner gave you so many high school memories. One night in 1859, Bunsen and his pal, the electrical wizard Gustav Kirchhoff, saw a neighbor's house on fire a mile (1.6 kilometers) away. They pointed their newly invented spectroscope at it and saw brief flashes of various colored lines — the now-familiar signatures of elements — as lead or copper pipes got hot enough to contribute to the inferno's light. The pair then realized they could determine the makeup of the Sun and stars in the same way! Bunsen wrote to a friend, "At the moment I am occupied by an investigation with Kirchhoff which does not allow us to sleep."

Who was the world's poorest astronomer? It's hard to determine the absolute most-broke celestial observer, but John Dobson actually boasted of his poverty and how he'd sometimes sleep inside his telescope. Moreover, his checking account was a reflection of his striking modesty. Once, when he was staying over at my home, he insisted that his invention, the Dobsonian mount that has revolutionized amateur astronomy by offering a non-wiggly, dirt-cheap mounting, didn't deserve praise at all. "It's just a lazy Susan," he insisted — a rotating disk like the kind you keep your salt and pepper shakers on. "Yet people use the term Dobsonian as if this is something groundbreaking."

Next, let's tackle an old, nagging issue: ***Can a celestial body make you cough?*** A May 16, 1921, article in *The New York Times* tells how surging voltage caused by the biggest solar storm since 1859 set a raging fire in the New York Central Railroad's 57th Street and Park Avenue control tower, affecting the surrounding apartment houses enough to cause widespread coughing and choking.

Does insurance cover meteorite damage? What's your guess? Well, after a 6-pound (2.7 kilograms) meteorite crashed through their Wethersfield, Connecticut, dining room ceiling in 1982, Bob and Wanda Donahue told me that their policy covered everything. It may have helped that they lived in a suburb of Hartford, nicknamed the Insurance Capital of the World.

What's the scariest observing setup? Near my home inside the Catskill Park, a 700,000-acre (283,300 hectares) mountainous preserve in upstate New York, I've twice seen a cougar during my nightly two-minute walk from my house to my observatory. I've also seen enormous black bears nearly monthly, except during winter when they're theoretically asleep. Walking alone at midnight, I swivel a flashlight, looking for glowing eyes. As you can imagine, my observations are often tinged with uneasiness. I'll bet many of you can easily top my celestial psychodrama, so please send in your story.

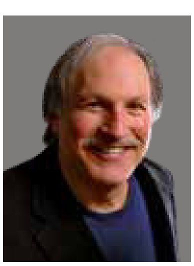
Have you ever wondered ***What the easiest major discovery was?*** I hang out with telescope operator Oscar Duhalde a few nights a year, whenever I'm in Chile at the Carnegie Institution for Science's Magellan Telescopes. It was on Feb. 23, 1987, he recounts, while walking from one dome to the next and glancing overhead as he always does, that he saw a star inside the Large Magellanic Cloud. "There's no star there," he said to himself. And at that moment, he discovered the brightest supernova in nearly 400 years.

Biggest cosmic rip-off? Twenty-four-year-old astrophysicist Jocelyn Bell Burnell found the first pulsar Nov. 28, 1967. Identifying a new kind of astronomical object should have won a Nobel Prize. And it did — except the Nobel committee solely awarded it to her postdoctoral research supervisor, Antony Hewish, even though it was Bell Burnell who had made the discovery.

What object has the most celestial synonyms? The very first asteroid was spotted the opening night of the 19th century and since then, the number of known asteroids has kept growing. About a thousand were recognized when my parents went to school. This year, we're up to a million. But hardly anyone seems content with that *asteroid* label coined by William Herschel. You can also call one a *planetoid*, although the International Astronomical Union prefers *minor planet*, while astronauts say *meteoroid* when a small one whizzes past the International Space Station. The largest is also termed a *dwarf planet*. Are five names too many?

If so, take heart, because NASA announced last summer that it intends to go in the other direction by eliminating names that might be considered offensive. So our final category is: ***What names should be eradicated from catalogs?*** NASA says the Eskimo Nebula will vanish: Starting this year, they'll only refer to it by its admittedly catchier designation of *NGC 2392*. Once they've eliminated the first four, perhaps we can consider the excess-*asteroid*-synonym issue balanced out.

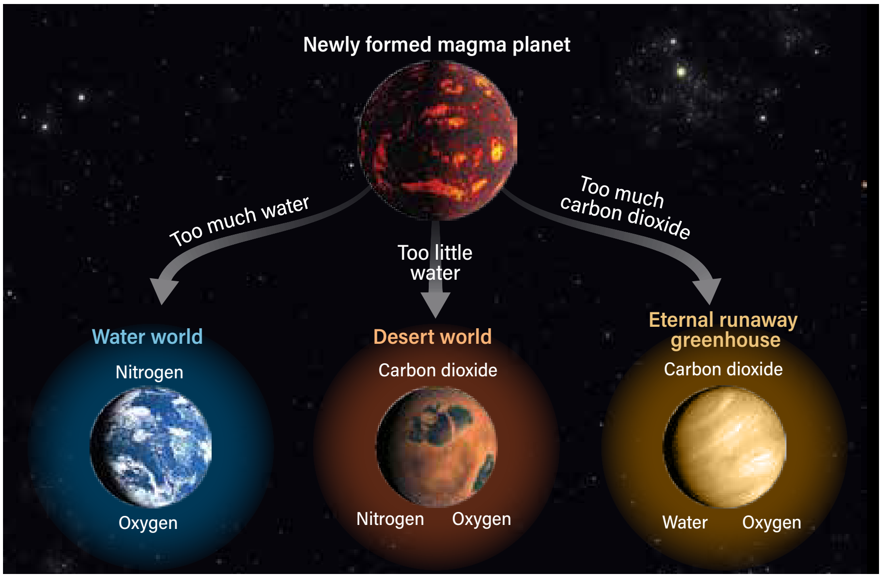
No matter how you classify things, this is one strange universe.



BY BOB BERMAN
Bob's newest book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

Oxygen may not be a sure sign of life



ASTRONOMY: ROEN KELLY, AFTER J. KRISSANSEN-TOTTON

THREE ROADS. New research has found three ways for an Earth-like planet around a Sun-like star to boast an oxygen atmosphere without life providing it. A lifeless planet with too much water, too little water, or a different initial makeup of elements could retain plenty of oxygen in its atmosphere.

Before life emerged on Earth, our planet's atmosphere was nearly devoid of oxygen. What little oxygen existed was taken up by the young planet's oceans of magma and, later, other forms of geological activity, keeping it locked in the surface, rather than remaining in the air. That only changed a little more than 2 billion years ago, when cyanobacteria appeared, which convert carbon dioxide to oxygen. Over 10 million years, life produced enough oxygen for it to become the second-most prevalent component of Earth's air.

Due to this history, astronomers have long believed oxygen is an excellent marker of life, or biosignature. They have even designed many next-generation telescopes with the ability to detect it in exoplanet atmospheres. But a new paper published April 13 in *AGU Advances* uses computer modeling to show that, in a variety of scenarios, rocky Earth-mass planets around Sun-like stars can develop oxygen-rich atmospheres without the presence of life. This means oxygen might not be the smoking gun researchers once hoped.

One such scenario is a water world with oceans whose volume is 50 times greater than Earth's oceans. All that water exerts pressure on the planet's crust, shutting off the geologic processes that remove oxygen from the atmosphere, like weathering and the melting of rock.

The second scenario is the opposite: A desert world with less than three-tenths the water in Earth's oceans that ends up with a solidified surface and a "steam atmosphere" of water vapor for a period of about a million years. This temporarily provides a big reservoir of atmospheric oxygen, as sunlight breaks up the water molecules and the planet's solid surface can't remove any oxygen, so it stays in the atmosphere.

Finally, a world with a higher concentration of carbon dioxide than early Earth can experience a runaway greenhouse effect that prevents oceans from forming in the first place. It's also too hot for elements to exist in the planet's mantle that would normally sequester oxygen through chemical reactions.

Despite these results, the prognosis for oxygen as a biosignature is still good. "There are other observations you can make to help distinguish these false positives from the real deal," study first author Joshua Krissansen-Totton of the University of California, Santa Cruz, explained in a press release. It seems astronomers will simply have to be a bit more discerning once they finally get a good peek inside the atmosphere of a promising Earth-like exoplanet.
—ALISON KLESMAN

COSMIC DANCE OF BINARY BLACK HOLES

Like two ballet dancers spinning on a grand stage, these supermassive black holes gracefully sweep toward one another in a visualization created by NASA's Goddard Space Flight Center. Surrounding each black hole is an accretion disk, a superheated soup of material that swirls around before flowing inward like water disappearing down a drain. Light from the accretion disks, colored blue and red, shows how the extreme gravitational forces of the objects distort their appearance when one black hole crosses in front of the other. —HAILEY ROSE MCLAUGHLIN

BINARY BLACK HOLES: NASA'S GODDARD SPACE FLIGHT CENTER/JEREMY SCHNITTMAN AND BRIAN P. POWELL

Prepare for the Perseids

A rewarding meteor showers peaks this month.

The meteors from any single shower all come from the same source, a cloud of debris shed by a space rock during its trip around the Sun. As Earth's orbit takes us through that cloud, the meteors all seem to fall from the same specific region of the sky, called the radiant. This composite shows meteors streaking from the radiant during the Perseids' peak on Aug. 11/12, 2015. ALAN DYER

Have you ever seen a meteor streak through the sky? If you're a long-time backyard astronomer, you've probably seen hundreds, if not thousands. And even those unfamiliar with the night sky will likely have glimpsed at least a few "shooting stars" over the years.

That's because meteors are far more common than most realize. In fact, as many as a half-dozen sporadic meteors zip across the sky every hour. So, even during a brief evening outing, you've got a good chance to spot one. Those odds dramatically increase during a meteor shower, too. And wouldn't you know it, on the evening of Aug. 12/13, we'll be entertained by the peak of one of the best showers of the year: the Perseids.

Like most meteor showers, the Perseids owe their existence to a comet — in this case, periodic Comet Swift-Tuttle. As this cosmic relic orbits the Sun, it leaves behind a trail of particles the size of sand grains. Whenever Earth intersects Swift-Tuttle's orbit and passes through this debris field, we see a surplus of meteors. Each flash across the sky signifies the fiery death of one of those tiny space crumbs, as it tears through Earth's atmosphere and succumbs to the heat of friction. Because this falling space dust comes from the same place, Perseid meteors all appear to streak outward from a specific region, called a radiant. In this case, the radiant is located near the northern part of the constellation Perseus, hence the shower's name.

The farther from the radiant, the longer the meteor's streak.

People have been admiring the Perseids for almost 2,000 years, with the earliest reference coming from a Chinese observer in A.D. 36. Today, the Perseids are the most observed of all meteor showers. That's not because they're the richest (that title would go to the December Geminids), but because they occur at a time of year when warm evening temperatures make for comfortable observing for many.

Here's what you'll want to do to get the most out of this year's Perseid display: In the days leading up to peak activity, pick out an observing site that's far from bright lights and affords as open a view of the sky, especially toward the northeast, where the shower's radiant will be. As with most meteor showers, the Perseids don't really kick into high gear until after midnight. However, you can begin to see activity around 10 P.M. to 11 P.M. on the evening of Aug. 12, when Perseus has risen above the northeast horizon. This isn't a sprint, so you'll want to stay relaxed and plan to observe from a lounge chair. If you live in northerly locations, make sure to dress in warm layers and bring a blanket. For those in more southerly regions, don't forget the insect repellent.

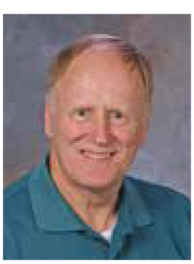
If you've never before witnessed a meteor shower, be forewarned that it isn't really a "shower." It's more of a slow — though beautiful — drip from a leaky faucet. Even a rich shower like the Perseids produces just one meteor every minute or so. Still, that's a pretty impressive rate, especially to someone who has never before seen a meteor.

What makes watching the Perseids, or any meteor shower for that matter, so riveting is the fact that you don't know exactly where or when the next flash will appear. The farther from the radiant, the longer the meteor's streak. In fact, a Perseid coming straight at you from the radiant will appear as a mere spark of light. Have no fear, though; it will have vaporized while still 50 to 60 miles (80 to 97 kilometers) above ground. Most Perseids will be roughly as bright as a 2nd- or 3rd-magnitude star. But there's always the possibility of an exceptionally brilliant meteor — called a fireball — that's bright enough to cast a shadow, as well as leave a luminous afterglow in its wake. One final note: These meteors move fast, traveling at some 37 miles per second (60 km/s)! That means the typical Perseid is visible for barely a second or two.

In the days following the 2021 Perseids, you may feel one of two emotions — elation, if you've seen dozens of meteors, or frustration, if you've been clouded out. In either case, the Perseid meteors return every August (although the 2022 visit will be hampered by a Moon that's just two nights past Full). There are also other annual meteor showers you can enjoy. Your next best bet is the Quadrantid shower, which will peak on the evening of Jan. 2/3, when the New Moon won't wash anything out.

For more information on observing meteors and showers, visit the websites of the American Meteor Society (www.amsmeteors.org) and the International Meteor Organization (www.imo.net). Alternatively, you can refer to the annual edition of the Royal Astronomical Society of Canada's *Observer's Handbook*, which devotes an entire section to meteor observing.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: a "Stella" variable star. Clear skies!



BY GLENN CHAPLE
Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple**

Titanium debris could solve supernova mystery

NASA's Chandra X-ray Telescope has detected a stable form of titanium among the debris of the supernova remnant Cassiopeia A. The find could help resolve a long-standing mystery about how such stellar explosions occur.

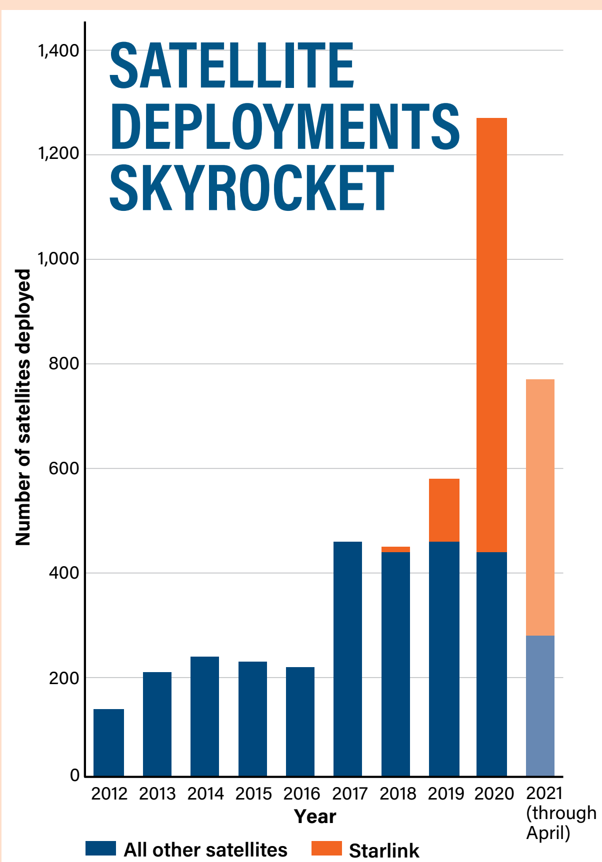
Astronomers believe that when a massive star dies, the star's material falls inward and rebounds against its dense core as it becomes a neutron star. This creates shock waves that move outward through the star, ripping it apart in a supernova. But there's a snag: In computer simulations, these shock waves quickly lose momentum, stalling out inside the star's interior before they can cause a stellar explosion.

Only accounting for the effects of neutrinos — lightweight particles created in the star's collapse — solves the problem. They prompt the creation of hot bubbles of material that quickly expand away from the newly formed neutron star, providing the shock waves with the energy they need to keep going. But evidence for such neutrino-driven bubbles has been absent — until now.

Recent Chandra observations of Cassiopeia A, one of the Milky Way's youngest supernova remnants, have revealed it contains a stable isotope of titanium never before seen in any supernova. Different isotopes of a given element all have the same number of protons but different numbers of neutrons. While other unstable isotopes of titanium had previously been detected in supernova remnants, including Cas A, stable titanium had not.

What Chandra saw — stable titanium alongside elements such as chromium and iron in fingerlike structures — matches what's predicted to form in the temperature and density conditions of neutrino-driven bubbles. So, these findings provide a significant piece of evidence that the neutrino-driven supernova theory is correct, at least for explosions like Cas A. —A.K.

BLAST SITE. In this composite image of Cassiopeia A, titanium is colored blue, iron is colored orange, oxygen is colored purple, and the ratio of silicon to magnesium is colored green. Optical light is shown in yellow. The titanium shown here is an unstable isotope previously imaged by NASA's NuSTAR satellite; the stable titanium discovered by Chandra is not shown.



UP AND AWAY. The number of satellites being launched into Earth orbit every year has been on a steady long-term uptick, thanks to the rise of new spacefaring nations and commercial space operators. But in the past two years, the number has grown at an unprecedented rate — almost entirely due to SpaceX and its Starlink internet-providing satellites. After the launch of a pair of test satellites in late 2018, SpaceX has increased its cadence of launches and grown the constellation to over 1,400 satellites as of May 2021. In March, Starlink had its biggest month yet, with three separate launches deploying a total of 180 satellites — more than were launched in 2012 by all nations and operators combined. —M.Z.

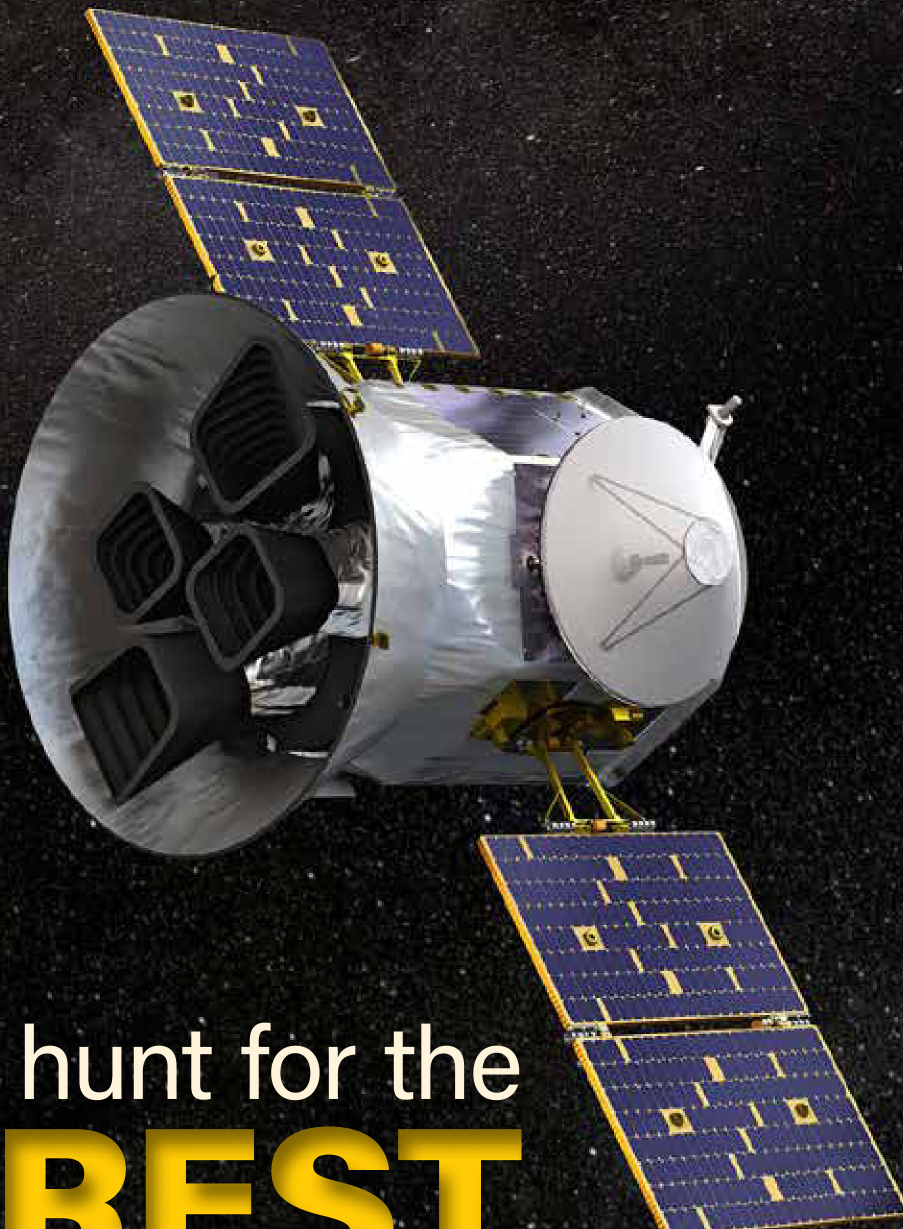
5,000

The amount, in tons, of extraterrestrial dust that falls to Earth each year, as determined from measurements of micrometeorites in melted snow at Concordia Station in Antarctica.

CASSIOPEIA A: CHANDRA: NASA/CXC/RIKEN/T. SATO ET AL.; NUSTAR: NASA/NUSTAR; HUBBLE: NASA/STSCI

ASTRONOMY: ROEN KELLY

The Transiting Exoplanet Survey Satellite (TESS) uses four identical CCD cameras to methodically search nearly the entire sky for exoplanets circling bright, nearby stars. Its data are released to the public with no proprietary period, opening up the field of exoplanet discovery to anyone with an internet connection. NASA'S GODDARD SPACE FLIGHT CENTER



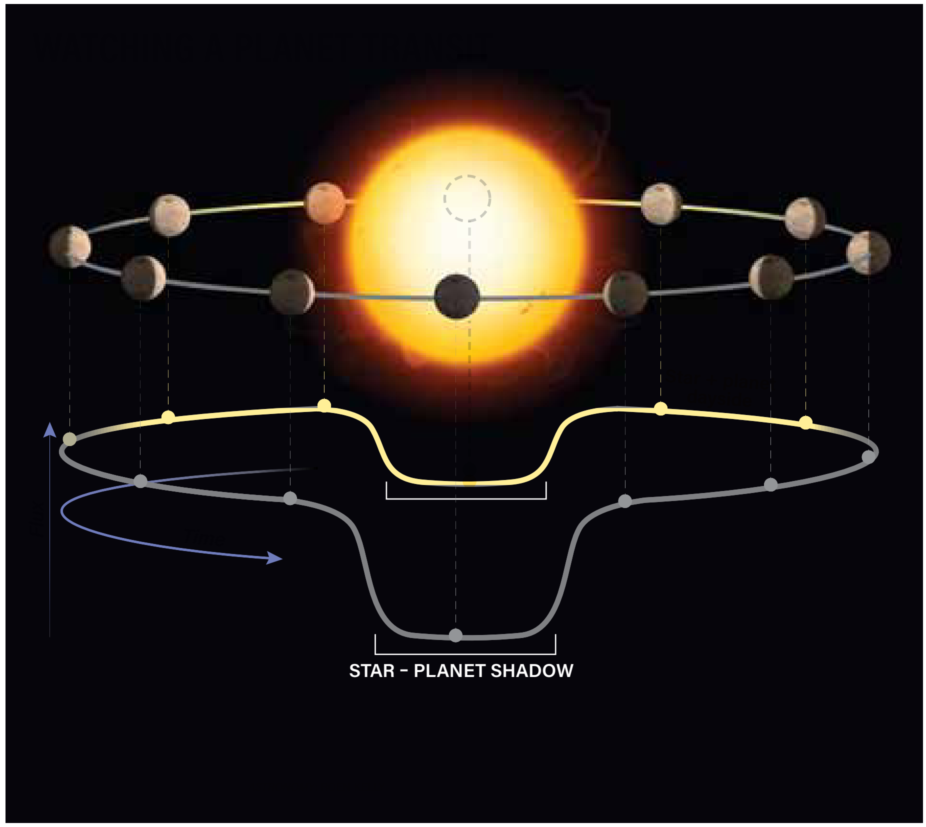
Inside the hunt for the NEAREST EXOPLANETS

TESS is revolutionizing our understanding of planets in the solar neighborhood. But finding new worlds is only the beginning.

BY GEORGE R. RICKER

IN 1995, astronomers discovered the first extrasolar planet orbiting a Sun-like star. Ten years later, exoplanet research remained in its infancy. Researchers still weren't sure whether planets circling other stars were plentiful or rare. So, members of my small satellite research group at MIT's Kavli Institute for Astrophysics and Space Research opened discussions with our neighbors at the Harvard-Smithsonian Center for Astrophysics (CfA). We pondered how we might repurpose the High Energy Transient Explorer-2 (HETE-2), which we had launched in 2000, to search for signals from extrasolar planets as they passed in front of their host stars.

We knew that our MIT-built star trackers were capable of detecting changes of as little as 0.1 percent in a star's brightness. This level of precision would allow us to spot transits of close-in Jupiter-sized planets — so-called hot Jupiters — orbiting solar-type stars. So, in 2005, we proposed to NASA that HETE-2 be assigned a new task and a new name. Rechristened the Hot Exoplanet Transit Experiment-Survey (HETE-S), it would carry out a nearly all-sky survey for transiting hot Jupiters at low cost (approximately $2 million per year) for five years. Unfortunately, NASA declined our proposal, noting that the considerably more capable Kepler Space Telescope — a much larger, $600 million mission dedicated to finding exoplanets by watching them transit their host stars — would soon launch.



NASA EXPLORERS MISSIONS

NASA Explorer-class missions cover a range of scientific goals. Each class is characterized by a budget cap for total cost (in USD) to NASA that includes mission definition, development, operations, and data analysis.

Medium-Class Explorers (MIDEX)
MIDEX missions have a budget cap of $180 million to $200 million.

Small Explorers (SMEX)
SMEX missions are capped at a total cost of $120 million.

University-Class Explorers (UNEX)
UNEX missions are launched via low-cost methods and capped at a total cost of $15 million.

Missions of Opportunity (MO)
These are part of non-NASA space missions and capped at a total cost of less than $55 million to NASA. *—Alison Klesman*

So, HETE-S never came to be. But from its conception was born the Transiting Exoplanet Survey Satellite (TESS). This mission is the result of more than a decade-long effort, with the primary goal of discovering transiting exoplanets in our solar neighborhood that are ripe for follow-up with the next generation of telescopes.

TESS is born

Although NASA rejected our proposal for HETE-S, we realized that a small satellite based upon HETE-2 and equipped with newer cameras could come in at a low enough cost for private funding. This new satellite, which we referred to as TESS-P (P for private), could carry out a shallow wide-field survey of the entire sky, complementing Kepler's 100-square-degree deep narrow-field search by covering a field 400 times greater.

During 2006 and 2007, the Kavli Foundation, the Smithsonian Astrophysical Observatory, Google, and a group of MIT departmental and private donors sought funding for TESS. Unfortunately, the Great Recession intervened and the majority of our prospective donors could no longer fund our plan.

Thus, when NASA announced an Astrophysics Small Explorer (SMEX) mission solicitation in 2008, we commenced work on our concept as a SMEX mission with only two months to go before the December proposal deadline. TESS survived as one of three mission proposals selected for a detailed Phase A study; unfortunately, it was not selected for flight following Phase A completion in 2009.

We immediately began planning for the next NASA solicitation, for which proposals were due in 2011. Yet again, NASA selected TESS for a year-long Phase A study, this time as a Medium-Class Explorer (MIDEX) mission. We were met with success: TESS was selected and funded as the MIDEX winner in April 2013!

A SpaceX Falcon 9 rocket carries TESS aloft from Cape Canaveral Air Force Station in Florida at 6:51 P.M. EDT on April 18, 2018. NASA/KSC

Each of TESS's CCD cameras, visible here as four cones with black covers at the top of the spacecraft, has a 24° by 24° field of view and functions as 64 million tiny light meters. Each pixel is 15 micrometers square. ORBITAL ATK

During the next five years, we assembled a highly skilled and dedicated team to design, build, fly, and extract scientific data from TESS. That team, which ultimately devoted more than a million hours to the effort, included members from MIT's Kavli Institute for Astrophysics and Space Research, MIT's Lincoln Laboratory, the Harvard-Smithsonian CfA, NASA's Goddard Space Flight Center and Ames Research Center, Orbital ATK (now part of Northrop Grumman), The Aerospace Corporation, Space Telescope Science Institute, and SpaceX. In addition, a science team comprising astronomers from more than a dozen universities worldwide collaborated to assemble the TESS observation program.

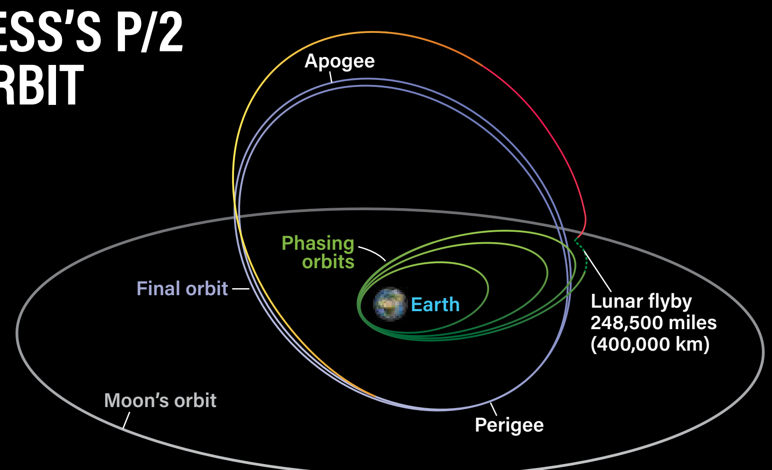
Getting a good view

TESS entered development in 2014 with the primary science goal of searching the entire sky for the best 1,000 small exoplanets within 200 light-years — i.e., the solar neighborhood. "Best" in this case means exoplanets with measurable masses, as well as atmospheres that can be studied with the upcoming James Webb Space Telescope (JWST). Essentially, TESS would be a finder scope for Webb, scouting for Earth-sized exoplanets orbiting the brightest Sun-like and smaller M-dwarf stars within about 200 light-years of our solar system. TESS would also serve as a bridge from the (now-defunct) Kepler mission to Webb, as well as other large exoplanet imaging space missions with launch dates in the 2030s and beyond.

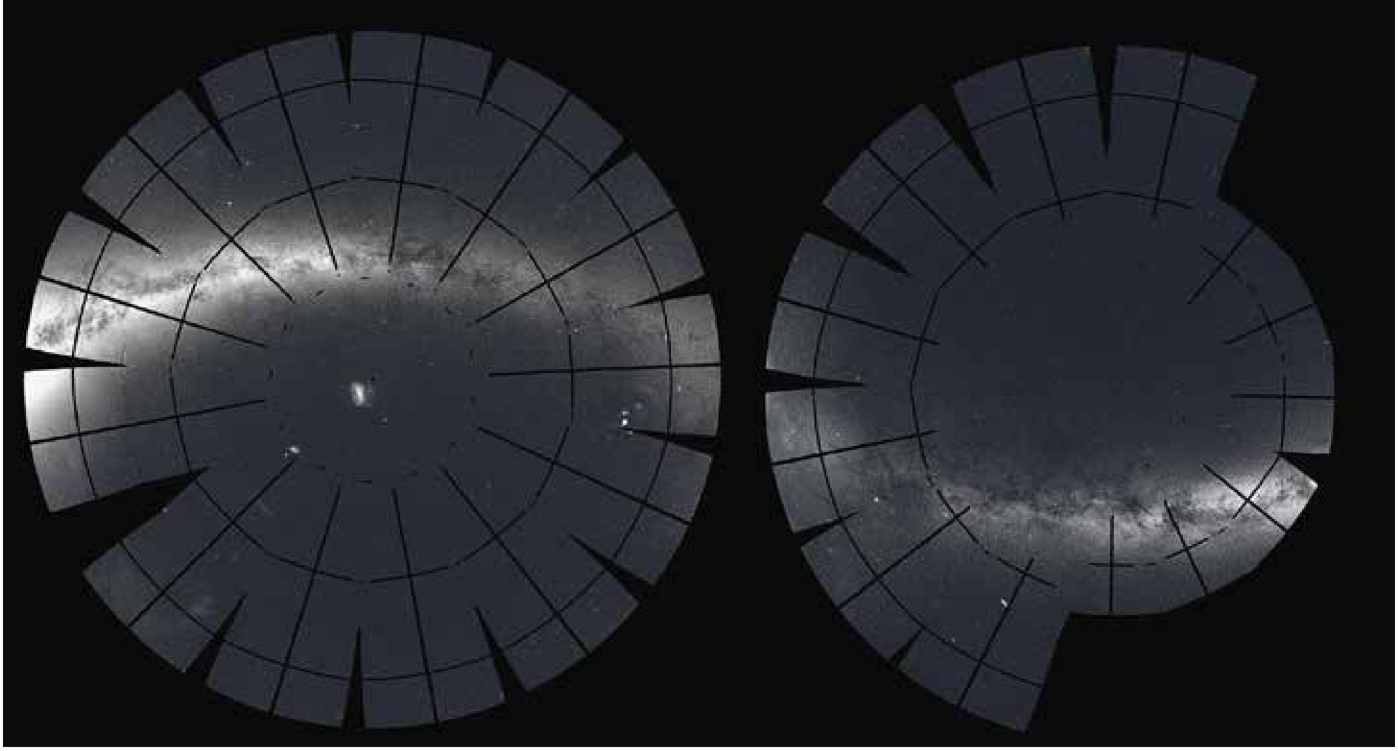
The most critical bit of mission planning was selecting an orbit for TESS that would provide a view free of obstacles — namely, Earth. TESS needed to continuously monitor a huge field of view (more than 2,000 square degrees) for weeks at a time. In order to find planets, it would need to see at least two or three transits — and a transit of a small planet might only last one or two hours every couple of weeks. Based on this data collection rate, TESS would also need to downlink enormous numbers of images for ground-based observers to search.

Orbits very distant from Earth — like Kepler's 6.2 million-mile (10 million kilometers) heliocentric orbit or JWST's planned 900,000-mile (1.5 million km) orbit around the Earth-Sun Lagrange 2 point — seemed desirable. But

TESS'S P/2 ORBIT



TESS's unique 13.7-day orbit around Earth puts the satellite in a 2:1 resonance with the Moon, meaning the spacecraft completes two orbits for every one orbit of our Moon. During that time, TESS comes as close to Earth as 67,000 miles (107,800 km) at perigee and swings as far away as 232,000 miles (373,400 km) at apogee. To reach this orbit, TESS underwent a series of three transfer orbits and a lunar flyby, ultimately arriving in its final P/2 orbit 42 days after launch. *ASTRONOMY*: ROEN KELLY, AFTER RICKER ET AL. (2014)

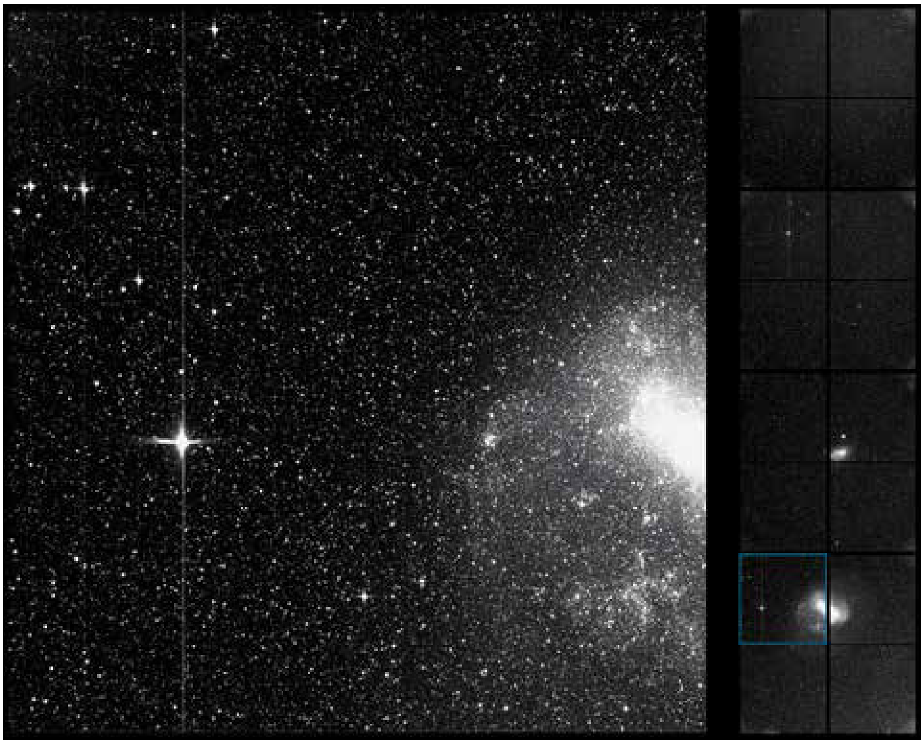


At the completion of its primary mission, TESS had mapped about 75 percent of the sky. Here, its complete view of the Southern Hemisphere appears at left and the Northern Hemisphere at right. The regions missing from the Northern Hemisphere map are areas TESS did not observe, to avoid picking up stray light from Earth or the Moon. NASA'S GODDARD SPACE FLIGHT CENTER

communicating from those distances would exceed any reasonable budget of antenna time a small mission could expect from NASA's Deep Space Network.

The solution turned out to be a new kind of elliptical orbit, in which the satellite spends part of its time close to Earth for data downlink but most of its time at a distance comparable to the Moon's distance from Earth. Generally, such orbits are notoriously unstable and can result in a spacecraft crashing into either the Moon or Earth within a couple of years. Our unique solution turned out to be an almost magical orbit in a favorable 2:1 resonance with the Moon's orbit around Earth. Since this specific so-called P/2 orbit had never been used previously in a space mission, our team spent an enormous amount of time analyzing how to establish and maintain it.

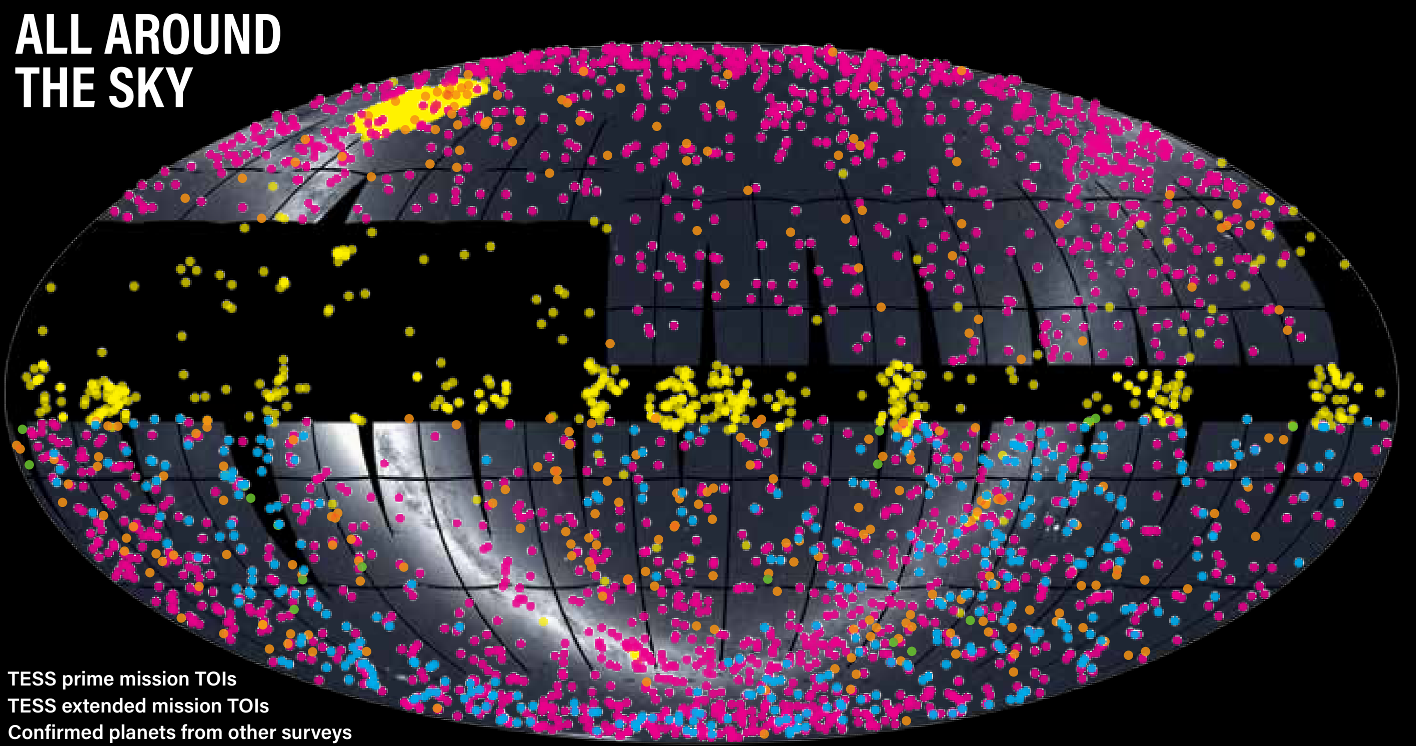
To be sure of our results, we had two different groups — one at The Aerospace Corporation and one at NASA Goddard — work independently on the calculations. In the end, our P/2 orbit was both elegant and practical. It even offered several major advantages, some of which surprised us — especially the excellent thermal stability of our cameras and the low radiation levels experienced by the spacecraft. Other advantages included high downlink rates and low stray background light.



The precision of TESS's cameras allows the mission to detect exoplanets with diameters half that of Earth orbiting solar-type stars. At the same time, the field of view of a single TESS camera dwarfs that of any currently operating or planned wide-field systems, either on the ground or in space. This full-frame shot of the sky near the South Ecliptic Pole shows clearly the Large Magellanic Cloud and the bright star R Doradus. It was taken as part of the spacecraft's first-light science images in August 2018. NASA/MIT/TESS

Primary mission success

On April 18, 2018, a SpaceX Falcon 9 rocket carrying TESS roared into space. TESS arrived in its final P/2 orbit 42 days later, and our primary mission's first survey observation began July 8. Over the next two years, TESS's four wide-field CCD cameras systematically stepped across the sky. During the first year, TESS observed 13 Southern Hemisphere "sectors" 24° by 96° in size for 27.4 days each. In its second year, TESS switched

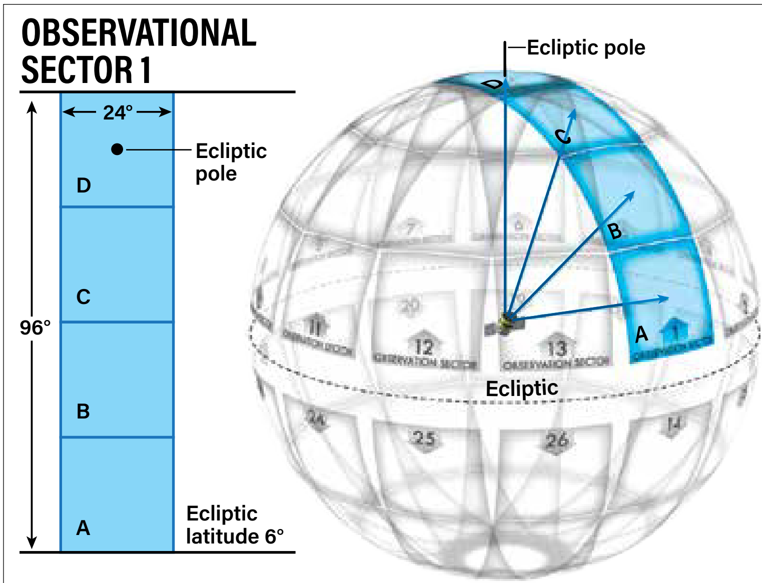


The nearly 3,000 TESS Objects of Interest (red and blue), or TOIs, are spread across the entire sky. By contrast, confirmed planets from other planet-hunting missions (yellow) are concentrated in only specific regions of the sky — an artifact of the search methods employed by those missions. *ASTRONOMY*: ROEN KELLY, AFTER NASA/MIT/TESS, ETHAN KRUSE (USRA), GREGGY BAZILE, NATALIA GUERRER

to observing 13 equally sized sectors in the northern sky.

The firehose of data from TESS's first three years has yielded thousands of new planet candidates spread over the entire sky. And the task of identifying the host stars for these candidates has fallen largely upon a small, dedicated group of analysts. Comprising primarily students and postdocs at MIT and the Harvard-Smithsonian CfA, this group — the TESS Objects of Interest (TOI) team — has been working for the past three years, examining light curves for more than 10 million stars brighter than 13th magnitude.

Their thousands of hours of effort have yielded approximately 3,000 new exoplanet candidates. We estimate that by the middle of this decade, this massive detective effort — which will be assisted by novel artificial intelligence methods currently under development — will have turned up as many as 10,000 new planet candidates. This immense collection should comprise essentially all of the best exoplanet candidates in the solar neighborhood for detailed follow-up and atmospheric characterization.



TESS divides each hemisphere of the sky into 13 distinct observational sectors measuring 24° by 96° each, observing a total of 26 sections between both hemispheres. The satellite views each sector for two orbits — a total of 27.4 days — before moving on to the next. *ASTRONOMY*: ROEN KELLY, AFTER RICKER ET AL. (2014)

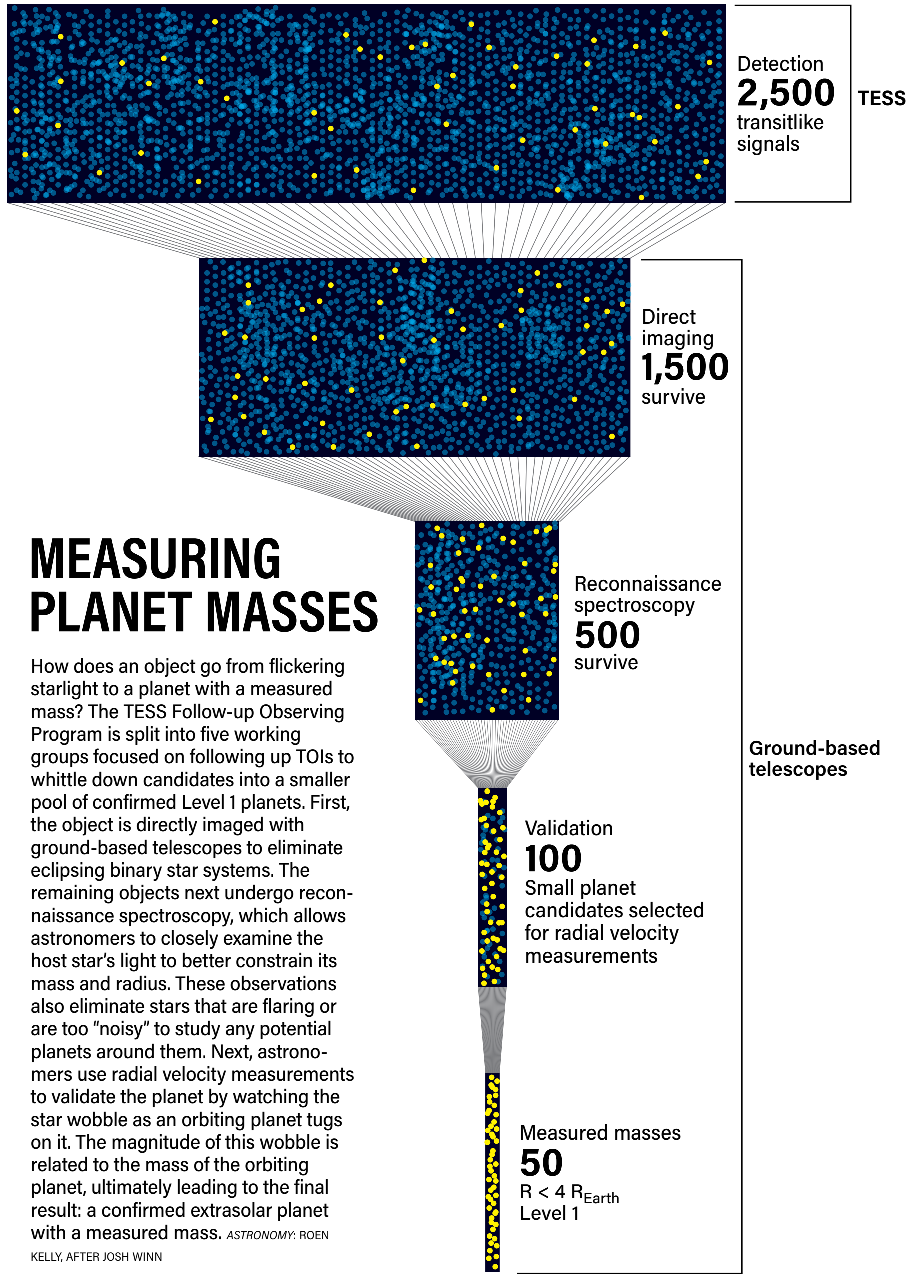
The TESS Follow-up Observing Program (TFOP), coordinated by our colleagues at the Smithsonian Astrophysical Observatory, is a worldwide effort of more than 550 astronomers at 100 institutions. These researchers sort through and follow up on this rich trove of TOIs using roughly 250 telescopes. TFOP astronomers have whittled down the 3,000 or so TOIs to about 100 so-called Level 1 confirmed TESS exoplanets. These Level 1 planets are all small, with radii less than four times that of Earth. Combined with the masses measured by the TFOP teams, we have confirmed that these small planets are indeed super-Earths and their slightly larger cousins with thicker atmospheres,

TESS IS FOR EVERYONE

From the start, we strongly advocated for TESS as a "people's telescope." As TESS scans the entire sky — including all the bright naked-eye objects — its perspective resembles someone contemplating a dark, cloudless night sky. Constellations are even readily recognizable in TESS images. (Of course, each 10-minute exposure goes 10,000 times deeper than the human eye!) Since launch, TESS has taken nearly 500,000 full-frame sky images, each with more than 10 million stars.

The TESS Guest Investigator (GI) Office solicits and selects proposals by astronomers worldwide to choose targets for science observations, and NASA can provide funding for U.S. astronomers. TESS's data are made accessible quickly with no proprietary period — not even for targets selected by individual astronomers or TESS science team members. In 2018, while the TESS team was developing and debugging its pipeline, the delay from receipt of raw data to production and release of calibrated images and light curves was about two to four months. By early 2020, the time required to deliver calibrated data had dropped to about one month. Now, in 2021, the delivery time is just a few days.

Today, the full TESS datasets are hosted as they arrive from space, orbit by orbit and sector by sector, with the help of the TESS GI Office at NASA's Goddard Space Flight Center and a public TESS archive at MAST. Their assistance has made the TESS data available for immediate downloading by anyone on Earth with access to an internet browser, at https://archive.stsci.edu/missions-and-data/tess. — *G.R.R.*



MEASURING PLANET MASSES

How does an object go from flickering starlight to a planet with a measured mass? The TESS Follow-up Observing Program is split into five working groups focused on following up TOIs to whittle down candidates into a smaller pool of confirmed Level 1 planets. First, the object is directly imaged with ground-based telescopes to eliminate eclipsing binary star systems. The remaining objects next undergo reconnaissance spectroscopy, which allows astronomers to closely examine the host star's light to better constrain its mass and radius. These observations also eliminate stars that are flaring or are too "noisy" to study any potential planets around them. Next, astronomers use radial velocity measurements to validate the planet by watching the star wobble as an orbiting planet tugs on it. The magnitude of this wobble is related to the mass of the orbiting planet, ultimately leading to the final result: a confirmed extrasolar planet with a measured mass. *ASTRONOMY*: ROEN KELLY, AFTER JOSH WINN

sub-Neptunes. Furthermore, an important subgroup of these Level 1 planets is Earth-like in both size and mass.

There are many other planets of varying sizes among the TESS planet candidates. And about 25 percent of TOIs are not planets at all, but distant eclipsing binary stars, whose eclipses can mimic exoplanet transits. Ongoing observations with higher-angular resolution telescopes, such as the Gaia space mission, will allow astronomers to separate these systems from real transiting planets.

TESS is also revolutionizing the study of multiplanet systems, especially those with six or more worlds co-orbiting their host star. Such systems were initially discovered by Kepler and the TRAnsiting Planets and PlanetesImals Small Telescope–South (TRAPPIST) survey telescopes. Unfortunately, these early discoveries orbit relatively faint stars — typically 14th magnitude — making them difficult to study.

As of early 2021, TESS has found more than 80 new multiplanet systems. Four recent discoveries, each with four or more planets, are much closer to Earth than the Kepler and TRAPPIST systems and thus have stellar hosts that appear 30 to 50 times brighter. These are much easier for follow-up observers to study. Brighter host stars also make it easier for JWST and the next generation of giant 30-meter class ground-based telescopes to investigate these planetary atmospheres via spectroscopy. This is because brighter stars mean shorter observations can still detect any potentially biologically interesting signatures in a planet's atmosphere as light from the host star filters through it.

Extended mission

After completing its initial planned two-year survey in July 2020, TESS embarked on a 26-month extended mission. Approved by NASA, this extension allows TESS to search for planets around

NASA'S GODDARD SPACE FLIGHT CENTER/CHRIS SMITH (USRA/GESTAR)

NOT ALL PLANETS

TESS was designed, funded, and built to identify transiting planets. But the very nature of its survey means it also catches plenty of so-called transient events that are *not* planetary transits. From eclipsing binary stars and supernovae to outbursts from nearby comets and far-flung supermassive black holes, TESS has seen it all. Although these events don't add to the catalog of known extrasolar planets, they still provide vital data for astronomers studying many other aspects of our universe.

TYC 7037-89-1: Located about 1,900 light-years away in the constellation Eridanus, TYC 7037-89-1 (also known as TIC 168789840) is a multiple-star system discovered within the TESS data. This unique six-star system is composed of three eclipsing binaries, meaning every star in the system undergoes eclipses as seen from Earth.

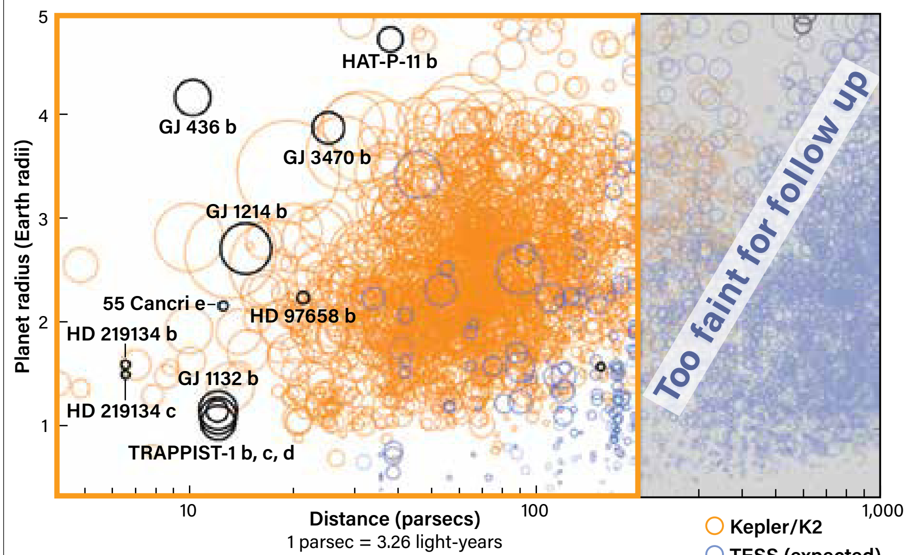
Nu (ν) Indi: TESS asteroseismology observations of this bright, naked-eye star have enabled astronomers to date the past merger of a satellite galaxy with the Milky Way to 11 billion years ago.

ASASSN-14ko: The galaxy ESO 253–3 contains an active supermassive black hole that belches out flares every 114 days (pictured at top in an artist's concept). TESS has been instrumental in helping researchers study these outbursts, which astronomers now believe occur as the black hole slowly nibbles away at an orbiting star during every closest approach.

Comet 46P/Wirtanen: When Comet 46P/Wirtanen swung near the Sun in late 2018, TESS was there to watch. The satellite observed an outburst of ice, dust, and gas from the comet as it was heated by the Sun — the most comprehensive picture of this type of event to date.

Supernovae: Within its first month of observation in 2018, TESS spotted six distant supernovae in other galaxies. That's the same number of supernovae the Kepler Space Telescope observed in four years — and it was only the start. Since then, TESS has caught nearly 200 such events popping off all over the sky. *— A.K.*

FILLING THE GAPS



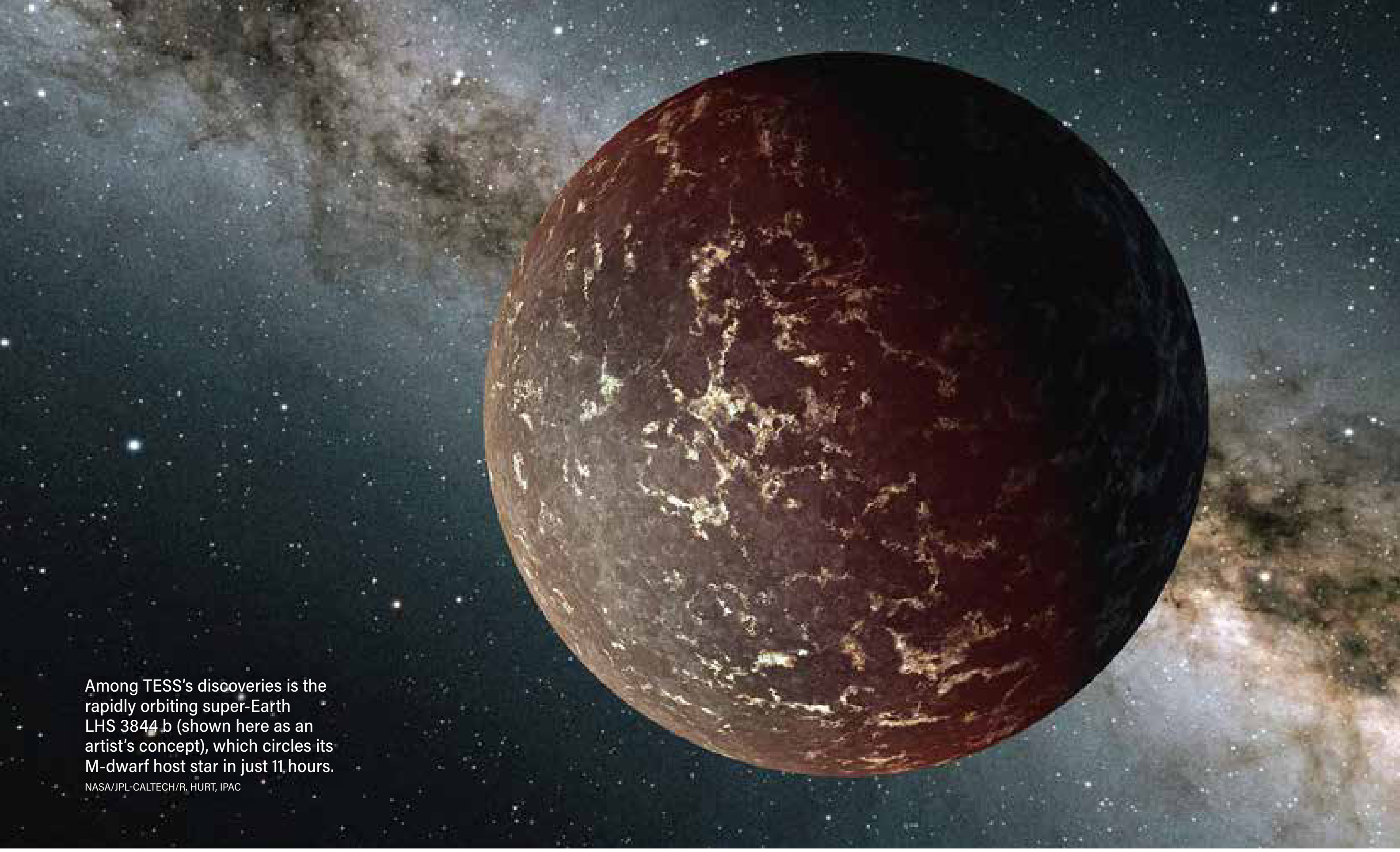
The TESS mission serves a unique function by identifying small extrasolar planets with radii just a few times that of Earth around bright, nearby stars. These particularly accessible host stars allow researchers to more easily and quickly follow up on newly discovered planets using ground- and space-based telescopes. ZACH BERTA-THOMPSON

even more distant stars, as well as follow up on some of the most exciting discoveries from the primary mission.

This first extended mission consists of three major initiatives: First, TESS will survey the sky a second time, covering the Southern Hemisphere again in the first year and the Northern Hemisphere in the second year. Additionally, TESS will spend 135 days exploring a 12°-wide band along the Ecliptic Plane, which was not probed during the primary mission because we were focused on fully covering the continuous viewing zones for JWST that surround the north and south ecliptic poles. The Kepler Space Telescope's K2 mission surveyed the ecliptic plane from 2014 to 2018. But measurement uncertainties in transit times mean that some K2 planets could effectively be lost as their real transit periods drift away from the measured (uncertain) periods over the half decade since their discovery, like two clocks ticking out of sync. TESS should recover a large fraction of these more than 400 confirmed K2 planets.

Second, TESS now takes full-frame images every 10 minutes, down from the primary mission's 30-minute exposures. More frequent exposures should help catch short-duration exoplanet transits as brief as 40 minutes. This will reveal more Earth-sized planets in the habitable zone of M-dwarf stars, which comprise approximately 75 percent of the stars in our survey. Overall, this improvement could triple the number of planets we expect to find from 50 to 150 — or more. Additionally, a new 20-second exposure capability has been introduced, which improves TESS's ability to detect and accurately measure stellar flares. It will also help TESS search for exoplanets orbiting white dwarf stars. Such transits had long been predicted when our extended mission was written, but were not confirmed until TESS discovered the first one in 2020: a Jupiter-sized planet orbiting the white dwarf WD 1856.

In 2020, TESS data revealed the Jupiter-sized exoplanet WD 1856 b, which orbits a white dwarf. This artist's concept depicts the unique system. NASA'S GODDARD SPACE FLIGHT CENTER



Among TESS's discoveries is the rapidly orbiting super-Earth LHS 3844 b (shown here as an artist's concept), which circles its M-dwarf host star in just 11 hours. NASA/JPL-CALTECH/R. HURT, IPAC

Finally, guest investigators will get to choose at least 80 percent of the extended mission's two-minute cadence mode targets. This mode downloads a small "postage stamp" of pixels around a single star in TESS's field of view every two minutes. This faster-paced observing can catch the beginning or end phases of bright planet transits. The remaining 20 percent of the extended mission's two-minute cadence targets will consist of the most promising TOIs from the primary mission.

A revolutionary impact

Thanks to our open policy and high data quality, the number and volume of TESS images and light curves downloaded from the Barbara A. Mikulski Archive for Space Telescopes (MAST) has been extraordinary. During 2020, users downloaded a total of 680 terabytes of data — about seven times the amount downloaded from either the Hubble or Kepler missions during that same period. In December 2020 alone, there were nearly 5 million requests for a total of about 50 TB of data.

During its 2019 review, NASA commended the TESS mission for "having a revolutionary impact on the fields of exoplanets and stellar astrophysics," as well as for "providing a model of how to build and serve a broad user base to maximize science return." As of March 2021, TESS had observed a total of 34 sectors and identified 2,597 TOIs. Of those, 755 have radii less than four times that of Earth and 120 are confirmed — thus far — as planets. Dozens more are underway.

The mission's first planet, Pi Mensae c, is a super-Earth four times more massive and twice as large as Earth, circling the naked-eye Southern Hemisphere star Pi (π) Mensae every six days. But TESS has also discovered TOI-700 d — an Earth-sized planet orbiting in its red dwarf host star's habitable zone, where conditions are right for a planet to maintain liquid water on its surface. And there's also LHS 3844 b, a super-Earth so close to its star that one year lasts just 11 hours and daytime temperatures soar to 989 degrees Fahrenheit (531 degrees Celsius).

TESS's data has provided observations for more than 300 scientific papers written in 2020 alone. And while most of those papers focus on new exoplanet discoveries, others are studies of the way stars vary, oscillate, spin, and produce flares. Citizen scientists can easily engage with TESS data through the Planet Hunters TESS Zooniverse project. This has led to the discovery of numerous planets, including TOI 1338 b — TESS's first circumbinary planet with not one, but two suns at the center of its orbit.

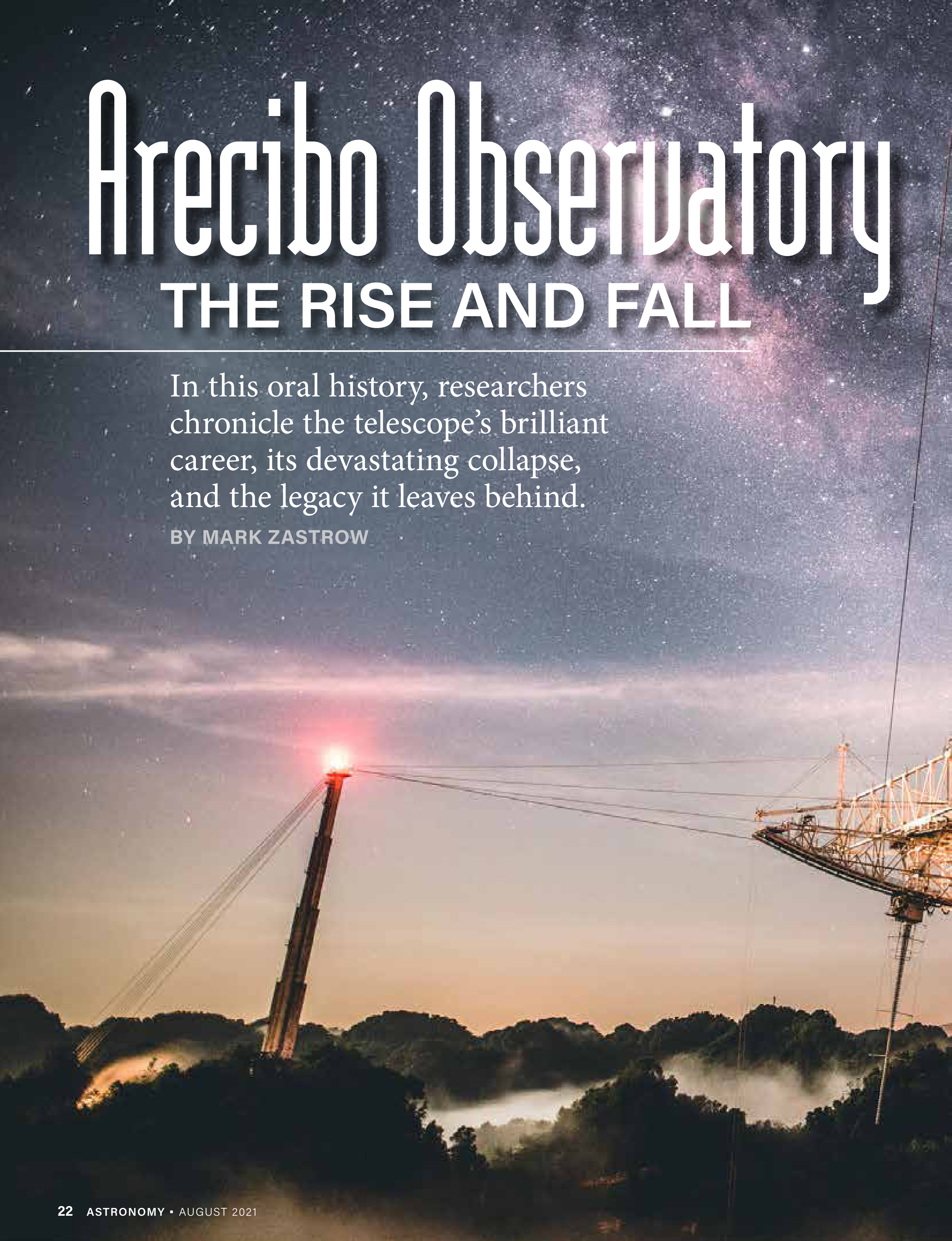
Now engaged in its second complete survey of the full sky, this small but powerful satellite will continue to reveal the wide diversity of worlds — like and unlike our own — that share our solar neighborhood. Next, it will be up to missions like NASA's JWST and Nancy Grace Roman Space Telescope, and the European Space Agency's Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) satellite, to delve into this long list of nearby worlds in greater detail, studying their atmospheres and compositions to learn more about how exoplanets form and evolve. Perhaps one of these observatories will even hit the jackpot: discovering potential signs of life on a planet first identified by TESS.

George R. Ricker *is principal investigator for the TESS mission. He also serves as director of the Detector Laboratory and is a senior research scientist at the MIT Kavli Institute for Astrophysics and Space Research.*

Arecibo Observatory
THE RISE AND FALL

In this oral history, researchers chronicle the telescope's brilliant career, its devastating collapse, and the legacy it leaves behind.

BY MARK ZASTROW



"The control room had this incredible view of the telescope. You're there working, focused. But there are times you remember, you're here, you're controlling this huge instrument in your hands. What a magnificent thing. I mean, there's no way you can go throughout the night and not remember it. That is a constant. It never grows old." —Carmen Pantoja

ARECIBO OBSERVATORY/NAIC

When the receiving platform at the legendary Arecibo Observatory came crashing down in a 900-ton heap of twisted metal on Dec. 1, 2020, it was a tragic end to a living monument with a storied history.

Upon opening in 1963, the telescope was called the Arecibo Ionosphere Observatory. Conceived by Cornell University electrical engineer William Gordon as an enormous radar to study the ionosphere, the facility was managed by Cornell and funded by the U.S. military's Advanced Research Projects Agency (ARPA), which was interested in using it to track nuclear missile launches. That Arecibo would become the world's most iconic radio telescope, discovering exotic stars and alien worlds, was almost an accident of history.

Astronomy talked to Arecibo researchers who worked at the telescope throughout its long history. Pioneering figures Gordon and astrophysicist Thomas Gold are no longer alive, but their voices appear here thanks to oral histories archived at the Niels Bohr Library at the American Institute of Physics (AIP). All interviews have been condensed and lightly edited for clarity.

The Arecibo radio telescope stood for 57 years, working on the cutting edge of astronomical research. For most of its lifetime, it was the largest single radio telescope dish in the world, only surpassed in 2016 by the Five-hundred-meter Aperture Spherical Telescope in China. ARECIBO OBSERVATORY/NAIC

William Gordon (at Arecibo's 40th anniversary, 2003): I do not know how we ever built it.

When we were talking about building it back in the late '50s, we were told by eminent authorities it couldn't be done. We were in the position of trying to do something that was impossible. It took a lot of guts. We were young enough that we didn't know we couldn't do it.

Daniel Altschuler, former Arecibo director: People came to look at the wonder. You know, it had these three towers pointing at the sky. To me, it was like a cathedral to science.

Abel Méndez, planetary astrobiologist, University of Puerto Rico, Arecibo: In *The Avengers*, there's a thing that one of the Avengers says to intimidate: "We have a Hulk!" For Puerto Rico, it's: "We have Arecibo!" Something to brag about, something to feel confident about. Puerto Ricans feel quite proud of the observatory.

THE EARLY YEARS

Gordon (1994): Honestly, the observatory was built to study the upper atmosphere. Radar astronomy and radio astronomy were essentially fringe benefits.

Donald Campbell, former Arecibo director: ARPA was interested in trying to figure out ways to detect incoming nuclear missiles by a wake that they might leave in the ionosphere. But even ARPA realized fairly early on while the telescope was being built that this probably wasn't going to be terribly useful [for detecting nuclear missiles] — as it wasn't, by the way.

Kevin Ortiz Ceballos @kortizceballos
What I will miss the most is the joy that we found at the Observatory. The sheer joy of sharing astronomical discovery with people from all walks of life, something we could do at Arecibo only because of where it was.
7:41 AM · Dec 1, 2020

While Gordon was primarily interested in studying the upper atmosphere, radio astronomers were intrigued as well. The field was still in its infancy, and the prospect of a facility as powerful as Arecibo drew attention. In 1959, Cornell's Dean of Engineering Dale Corson lured the brash British astrophysicist Thomas Gold from Harvard University to run a burgeoning astronomy program that would include overseeing Arecibo.

Thomas Gold (1978): Bill Gordon unfortunately didn't take kindly to that.

In 1960, Gordon moved to Arecibo to supervise its construction, leading up to its 1963 dedication. But he soon found himself in a power struggle with Gold, who oversaw Arecibo from Cornell's campus in Ithaca, New York.

Gordon: It was a matter of who was in control, I guess.

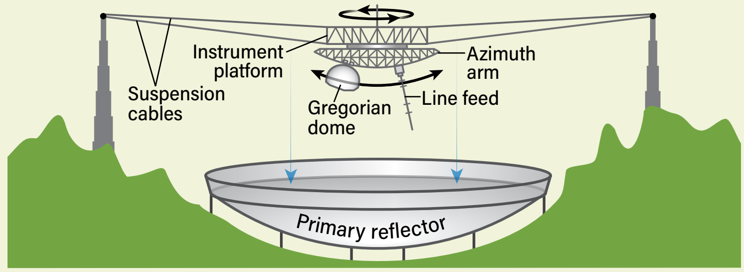
Gold: It's all very well to be responsible for the construction, but we had to build up teams of people to operate the thing and to use it for the many different purposes for which it could be used, including radio astronomy, which Bill Gordon knew nothing about.

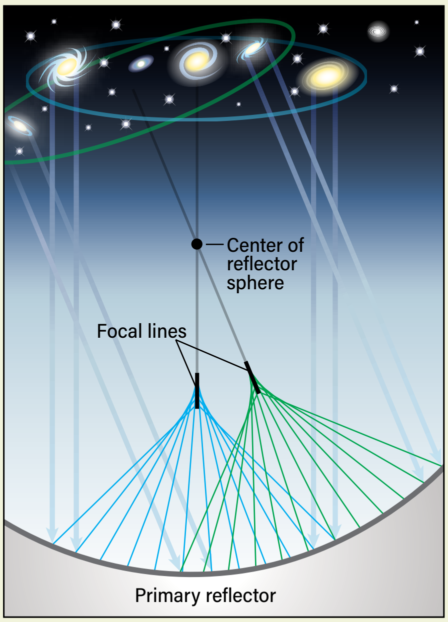
Gordon: It was Corson who finally, in 1965, asked me to come back to Cornell. If you ask me, I was mad at the time. I thought I was removed from a job that I deserved to have. I'm sure that Gold had talked him into it.

Gold is a very bright guy. He's cunning. He has lots of good ideas. Wait a minute. He has lots of ideas. Some of the

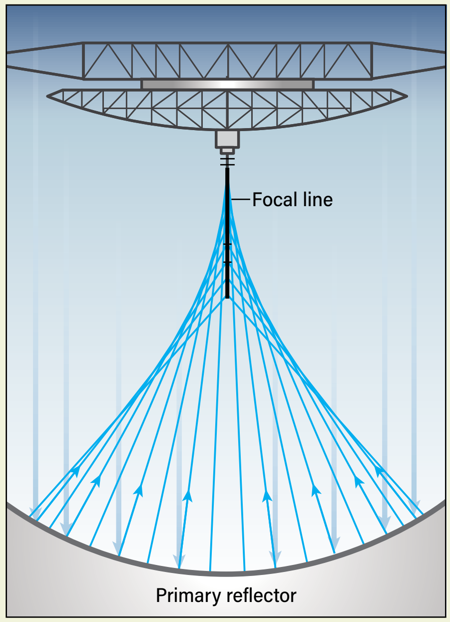
HOW ARECIBO WORKED

Arecibo's structure was, as William Gordon put it, "elegant in geometric terms. The triangle which supports everything is held by cables from three towers," he told the AIP, and "there's a circle hanging on the triangle." This circular track allowed the azimuth arm to rotate. The receiving equipment moved along the azimuth arm's arc, thereby changing its elevation. *ASTRONOMY*: ROEN KELLY

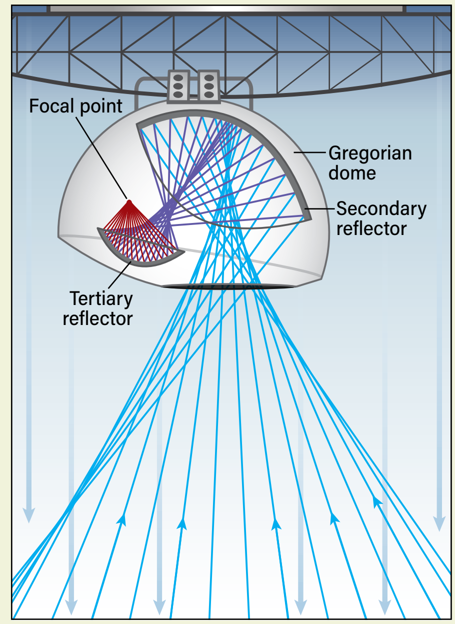




Because Arecibo's 1,000-foot-wide (305 m) reflector couldn't move, it was curved like a sphere so that the receiver could be aimed at any part of the dish, enabling the receiving beam to be pointed across the sky.



The downside was that, unlike a parabolic dish, a spherical reflector doesn't focus to a point — the reflected signals converge along a focal line. To capture the signal, a unique, 96-foot-long (30 m) receiver was built, called a line feed.



The shortcomings of a spherical primary reflector were rectified when the Gregorian dome was installed in 1997. It housed two curved reflectors to correct the aberration and bring the radio waves to a physical focus.

ideas are good. But the people around him are snowed trying to sort out the good ideas from the chaff.

Campbell: There was, oh, let's just say, different *visions* between Gordon and Gold. But that didn't affect relationships at the observatory. The big staff got along just fine with everybody. You always had occasional personal issues or something, but it was a very congenial group of people. Because to some degree, they were thrown together. And there was a lot of socializing that went on within the observatory, expatriate staff, et cetera.

It was a lot of fun, actually, frankly. *[Laughs.]* It had only been in operation for a little over a year when I arrived there. The staff was pretty young; there were quite a number of graduate students. Everybody was pretty excited about using it.

The Arecibo site lies in a natural concave sinkhole nestled in the karst mountains of Puerto Rico. ARECIBO OBSERVATORY/NAIC

ON THE PULSE

In 1967, British astronomer Jocelyn Bell Burnell discovered radio pulses emanating from objects in space that were quickly dubbed pulsars. This unexpected find put radio astronomy front and center — and Arecibo took on a starring role.

Campbell: Arecibo was perfect for pulsars. Normal radio telescopes weren't terribly well equipped to look at very fast, time-changing signals. But Arecibo was equipped to do just that, because of the radars.

Pulsar pulses aren't that different from radar pulses, and so Arecibo was not only the biggest, most sensitive telescope in the frequency range, but it was also by far the best equipment to do the work. So everybody converted over to doing pulsars, including me. *[Laughs.]* Pulsars made Arecibo's name, certainly in the radio astronomy community.

In 1969, ARPA's interest having run its course, the National Science Foundation (NSF) took over ownership of Arecibo. NSF designated Arecibo the National Astronomy and Ionosphere Center (NAIC) and retained Cornell to operate it. The first major

upgrade to the facility began in 1972 and was completed in 1974, greatly improving both its receiving and transmitting capabilities.

In the 1980s, pulsar astronomy continued to grow with the discovery of millisecond pulsars, which spin several hundred times per second. For Aleksander Wolszczan, who arrived at Arecibo in 1983 from his native Poland, it was a heady time.

Wolszczan: I would venture to say that that period, when I was just lucky enough to be there, was really the most productive period in Arecibo's history. There was a lot of stuff going on — I mean really, very good science.

Arecibo had very, very tolerant policies toward high-risk science, or attempts to do something extraordinary or something that wouldn't give you a guaranteed result. There was always a way to get some telescope time to test out some crazy stuff.

In this photo from February 2005, workers on the Gregorian dome prepare to install a new receiver, the Arecibo L-Band Feed Array (ALFA), dangling from a cable at the left. ACEVEDO, ARECIBO OBSERVATORY, CORNELL UNIVERSITY

In the mid-1990s, Arecibo underwent its second major upgrade, which included adding a Gregorian reflector to correct the dish's spherical aberration and replacing its line feed antennas with a multi-beam receiver. A more powerful radar transmitter was also installed, allowing the telescope to better image potentially hazardous near-Earth asteroids. Six sets of auxiliary cables were installed, two on each tower, to handle the 50-percent increase in platform weight.

Gordon (1994): I know what they're trying to do, and they're spoiling our elegant geometry by adding all kinds of extra cables. Apparently, the Gregorian is a heavier weight than the structure was intended to support.

REACHING OUT

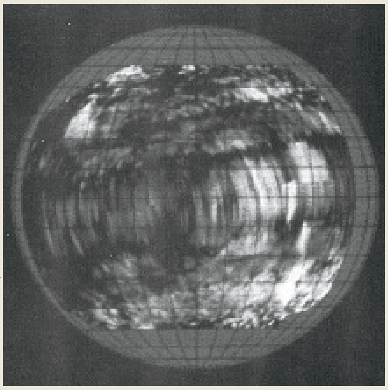
Around this time, Mayra Lebron, an undergraduate student in astronomy at the University of Puerto Rico (UPR) in Humacao, participated in a summer research program at Arecibo.

Lebron: One of my motivations was that I got to know that there were no Puerto Ricans working on the Arecibo Observatory. I said, "How come?" With time, you are expecting that many people from this area would start working as scientific staff at this place, but there were none.

OK, then I decided I want to study astronomy. But if I shall serve my country, it had to be in radio astronomy, because I wanted to come back and go to Arecibo.

Because UPR does not have a physics

VENUS REVEALED

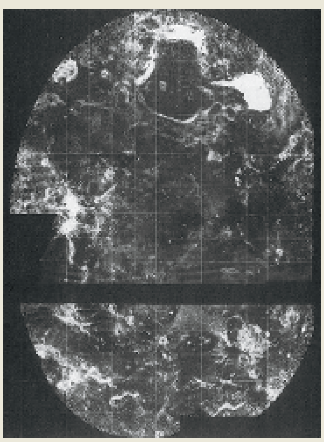


DONALD CAMPBELL, CORNELL UNIVERSITY

Donald Campbell arrived at Arecibo in January 1965, fresh from undergraduate studies in his native Australia. For his Ph.D. thesis, he tried using Arecibo's planetary radar to survey the surface of Venus, which is hidden below its clouds. But the first-generation line feed did not perform as hoped.

Campbell: This was the first time anyone had done something like this. Let me emphasize, it was somewhat of a gamble to build a spherical antenna when you didn't really have assurance that you could actually design a line feed. And unfortunately, the line feed turned out to be far less efficient than expected, by about a factor of two. So that limited the capabilities in terms of resolution as well.

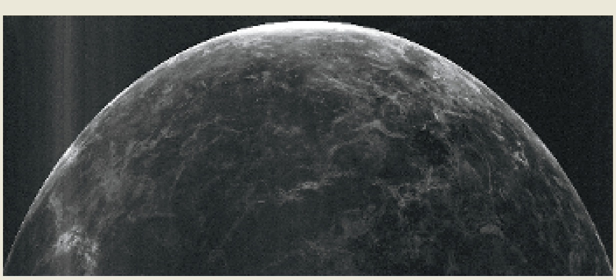
Campbell's initial planetary radar images (above) were not much more detailed than those from existing facilities. That changed in the 1972–74 upgrade, when Arecibo received a more efficient line feed and a new high-power transmitter.



NAIC/CORNELL UNIVERSITY/NSF

Campbell: We got much, much improved images of Venus (left) — good enough to see craters and volcanoes and various other features on the surface. So for the first time, there were images covering about 30 percent of the surface of Venus that that you could actually interpret in terms of surface geology, so to speak. That was pretty exciting.

With upgrades, over time, Arecibo's radar capabilities progressed, revealing ever-finer details on Venus' surface. The image below was produced in 2001 by Arecibo's radar transmitter; the Green Bank Telescope in West Virginia received the signal. Brighter areas correspond to rougher surfaces, while dark areas are smoother.

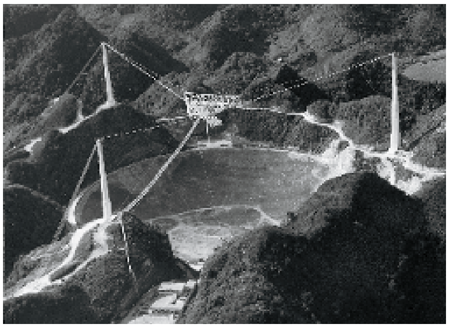


CAMPBELL ET AL., (NRAO/AUI/NSF); NAIC

Alessondra Springman @sondy
I was trained, trusted, and turned loose on the 1-megawatt radar. I worked with incredible humans from Puerto Rico, North America, and the rest of the world.
5:25 PM · Nov 19, 2020

Excavation is underway at the Arecibo site in this aerial photo from December 1960. ARECIBO OBSERVATORY/NAIC

The triangular platform that would support the telescope's receivers is hoisted into place in October 1962. ARECIBO OBSERVATORY/NAIC



Arecibo stands completed in its initial configuration in August 1963. The first reflecting dish is made of a wire mesh through which the valley below can be seen. The line feed hangs over the reflector like a needle. CORNELL UNIVERSITY, COURTESY OF AIP EMILIO SEGRÈ VISUAL ARCHIVES

An Arecibo worker performs maintenance on the wire mesh of the reflector dish, wearing ski-like boards to prevent tearing the surface. CORNELL UNIVERSITY, COURTESY OF AIP EMILIO SEGRÈ VISUAL ARCHIVES

A worker paints the structure of Arecibo's receiving platform some 450 feet (137 m) above the dish. DIVISION OF RARE AND MANUSCRIPT COLLECTIONS, CORNELL UNIVERSITY LIBRARY

Arecibo designer William Gordon stands on the catwalk over the dish that leads to the receiving platform. DIVISION OF RARE AND MANUSCRIPT COLLECTIONS, CORNELL UNIVERSITY LIBRARY

doctorate program, Lebron left the island after obtaining her undergraduate degree. She did her Ph.D. in Mexico, worked on the Very Large Array in New Mexico, and took a postdoctoral fellowship in Germany. Then, in 2002, NAIC director Paul Goldsmith called with an offer of a research position at Arecibo.

Lebron: He said, "Come now," and I just went. I said, "OK, now is the moment to come back." I took the position and was very happy, very excited to be back and in a research position at Arecibo. But I knew that it would be difficult — that I needed to build something for my community when I came back.

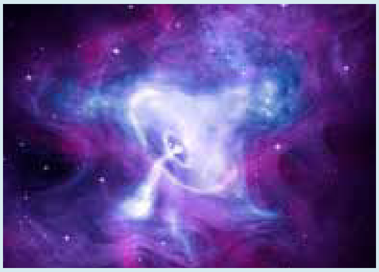
Lebron was the first of only two Puerto Rican astronomers who would ever serve on Arecibo's staff. However, a cooperative agreement with UPR allowed faculty members access to the observatory, including Carmen Pantoja, a native Puerto Rican and astronomer at UPR in San Juan.

Pantoja: I got an office at the observatory. I could come and go freely, I could integrate with the staff. That was excellent. In the summers, I worked with undergraduate students, helping with their research, but then spent the time at Arecibo.

PULSAR PIONEERS

Soon after Jocelyn Bell Burnell discovered pulsars, Thomas Gold proposed that they were rapidly spinning neutron stars with strong magnetic fields. This theory became widely accepted in 1968 when Arecibo revealed a pulsar in the Crab Nebula with a period of just 33 milliseconds.

In 1974, Arecibo nabbed another major pulsar find. At the time, the telescope was still undergoing upgrades and couldn't track. But the receivers could still listen for pulsars, scanning across the sky overhead as Earth rotated. During this time, Joseph Taylor and his graduate student Russell Hulse discovered the first binary pulsar system — a find that provided the first indirect evidence of gravitational waves and landed them a Nobel Prize in 1993.



The Crab Pulsar is pictured here in this composite image from three NASA space observatories: X-rays from Chandra X-ray Observatory (blue and white), optical from the Hubble Space Telescope (purple), and infrared from the Spitzer Space Telescope (pink). X-RAY: NASA/CXC/SAO; OPTICAL: NASA/STSCI; INFRARED: NASA-JPL-CALTECH

This artist's concept of the PSR B1257+12 planetary system depicts the two worlds that Wolszczan discovered in 1992 in the foreground. A third, much smaller planet, pictured in the background, was discovered in 1994. NASA/JPL-CALTECH

THE FIRST EXOPLANETS

In 1990, Arecibo underwent an extended period of maintenance.

Wolszczan: There were periodic inspections of the structure of the telescope. And during one, they actually discovered some signs of actual cracks in the structure supporting the platform, and they had to be replaced.

Though the telescope was immobilized, science could still be done.

Wolszczan: So I proposed to do a scientifically high-risk project, which was to look for millisecond pulsars away from the galactic disk. Most of the types of searches, including millisecond pulsar searches at the time, were really focused on the galactic disk and the galactic center.

Wolszczan found two pulsars — one of which, dubbed PSR B1257+12, proved particularly vexing. Millisecond pulsars typically have a white dwarf companion whose gravity would pull on the pulsar, altering the timing of its pulses, albeit in a regular way related to their pair's orbits. But the variation in this pulsar was too irregular — as if there were something else pulling on the pulsar. Wolszczan was awarded more observing time and used Arecibo to track the pulsar regularly, and a clearer picture emerged.

Wolszczan: A very interesting thing was that the amplitude of that effect was too small for a companion — or companions — to be stars.

So that was when I really kind of had a pause and began to think that I could be onto something really big — not just yet another binary millisecond pulsar, but something much, much more exotic than that. The pattern emerged really, very clearly: It was two super-Earth-mass companions orbiting the pulsar.

Wolszczan had discovered the very first confirmed exoplanets, another major feather in Arecibo's cap, and one that kickstarted the current golden era of exoplanet research.

The opening of a proper visitor's center in 1997 also raised Arecibo's local profile. The only facility of its kind in Puerto Rico, it featured exhibits, an auditorium, and an observing deck with a spectacular view of the radio dish.

Genesis Ferrir Imbert, undergraduate student, UPR, Rio Piedras: Every school, they always take you on field trips to Arecibo. You probably visit it like two to three times while you're growing up. That was the reason I initially got into physics — because of Arecibo and the astronomy that was developed there. I know a lot of students of physics, we've talked about this. And a lot of people feel exactly the same way.
Altschuler: Arecibo Observatory, after a long time of being an isolated island, became part of the community. It became a place of attraction, a place of inspiration for future scientists and education.

But of course, the Senior Review was blind to that.

UNDER PRESSURE

In 2006, NSF released a report of its astronomy facilities, known as the Senior Review, that sought to trim $30 million per year from their operating budget. It recommended closing Arecibo by 2011 unless other organizations could fund the telescope's $12 million annual budget.

Altschuler: I remember, even way before the Senior Review, that we were very worried about the future. And, of course, that didn't contribute internally to the morale of the scientific staff. Everybody was rumoring, you know, "They say they're going to close us," and all that. We lived always under that Damocles sword.

In 2011, after a competitive bid process, NSF awarded management of the facility to SRI International, a nonprofit research institute in California, under a reduced budget of roughly $8 million a year.

Campbell (then NAIC director): To be blunt, I think that was a serious mistake. Because Cornell brought not just the management side, they had a very active faculty involved with Arecibo. SRI didn't really have the same depth.

Through a spokesperson, NSF said its "decision making process is the gold standard in merit review. We are confident that the choice was made based on the best data points available at the time."

Pantoja: When the new administration came, everything changed, unfortunately.
Lebron: NSF decided to reduce the funds for Arecibo. And they decided to cut the money for the staff, too. And then I was one of the people that they took. They decided that they didn't want to support anymore the area of molecular lines in the high-frequency bands.

When they decided that, I was on maternity leave. It was not easy, and it wasn't that nice. When I came back to Puerto Rico, I was just recently married and then we decided to have kids.

This was the most difficult part. You

Marialis Rosario-Franco @multiversario
The loss of the Arecibo Observatory means grieving the dream of returning to my land to work as a radio astronomer whilst contributing to the development of a solid astrophysics program for the Caribbean youth.
8:26 AM · Dec 1, 2020

When an auxiliary cable came out of its socket on Aug. 10, 2020, it smashed through the reflector panels in the dish below. UNIVERSITY OF CENTRAL FLORIDA

know, this part is not solved in research. Men can work having a family. If a woman has kids, they're not serious in their job.

Lebron, Altschuler, and other Arecibo staff found positions at UPR and were able to continue using the observatory.

Lebron: I observe with Arecibo, I have my project with all the people, I continue doing like that. No one can stop me. *[Laughs.]* No one can stop me, you know. Doesn't matter! I exist!

Other astronomers, like Méndez, saw progress under new management. The handover to SRI — and a subsequent shift to a group led by the University of Central Florida in 2018 — marked an uptick in local students learning and working at Arecibo.

Méndez: That transformation — it was NSF. One of the requests of the NSF was more impact in the community, more education, more outreach. And I have to admit, the SRI proposal was much better in that area. I think that since the early days, Cornell was moving forward to be more open to the community — but, I will say, never enough.

THE COLLAPSE

Wolszczan: All stories have their beginnings and their ends.
Gordon (1994): When we first talked to engineers here about building this, that was one of the first questions they wanted to know: What's the lifetime? We batted that one around and around and finally said, 10 years. They were thinking of bridge cables. Once they even removed one cable just to look at it.

It's 30 years old. It's like a cat [that's] already had three of its nine lives. In many ways Cornell has taken good care of it.

Altschuler: Half of the Arecibo staff — more — was dedicated to maintenance. And they were led by an engineer of great knowledge whose name is José Maldonado. He's now 80-something. He knew the telescope like the palm of his hand. He had been there for 30 years and was engaged and contributed to all the upgrading that went on.

I remember when I was learning from him, he said, "Daniel, anything that breaks on the platform, I send my people up, and we fix it. I can go up there and fix anything you want. But if a cable is in bad shape, that's something that we can't allow."

He had a very, very strict inspection program. For the cables, he even had a little cart that hung from the cables from two wheels with a little motor and a basket. And a guy — which wasn't me *[laughs]* — would go all the way along the cable, inspecting visually for signs of corrosion, because this is embedded in humid, hot, and salty air.

He also invented a system which had compressors at the end of the cables that push hot or dry air through the interstices of the cable wires. So there was always a bit of positive pressure out the cable, so that humid air wouldn't be able to enter.
Pantoja: When I was a student, you would always see them painting, up and down. Lots of time spent on that.
Lebron: There was a painting crew that worked the whole year. You start painting in one corner, and then you start painting the other. Because if something fails and you have corrosion, *[claps twice]* you lose the platform. It will fall down.

Maldonado left the observatory after SRI took charge — a huge loss, in Altschuler's eyes.

Altschuler: It should have been NSF's responsibility to make

Arecibo's collapse was caught on video from the control room. After the remaining cables atop the southeast supporting tower gave way, the receiving platform careened across the dish from the two remaining towers as it fell to the ground. NATIONAL SCIENCE FOUNDATION

sure that this transition was done with care, especially with care of institutional memory.

Arecibo was not just a car you jump in and drive. Arecibo was a very special, peculiar beast and, as such, it had little screws here and there that you had to know about so that things went smoothly. And a particular great piece of knowledge left the observatory when Engineer Maldonado left.

NSF says the forensic analysis and evaluation to understand the causes of the collapse is ongoing.

Méndez: I think the most damaging thing was Hurricane Maria in September 2017. I was thinking that the winds will be so strong that I was expecting the Gregorian to collapse, to fall away.
Altschuler: Hurricane Maria really did do damage. One of the antennas fell. People tell me that the platform was shaking like this *[shakes his arms vigorously]*, and this is a 900-ton platform hanging from cables. What does that do to a cable, when you start tensioning and releasing tension like that?

Repairs to the transmitter from Maria-related damage were still ongoing in early 2020 when the COVID-19 pandemic struck. Most Arecibo users switched to remote work, like the rest of the world. Student visits to the telescope were put on hold.

They would never resume.

On Aug. 10, 2020, one of the auxiliary cables holding the weight of the Gregorian dome came out of its socket atop the southeast supporting tower, striking the dome and crashing to the dish below.
Méndez: I was surprised, but I was not that worried. I thought well, this is an auxiliary cable, it will be fixed. Maybe in a few months, maybe a little bit more. I was more sorry for my students, telling them, "OK, we have an issue. Our observations were canceled."

But others saw a grave threat to Arecibo.

Lebron: When I saw that they didn't know why this cable came out and broke, I said, "OK, that's very, very, very bad." If the ones that have the task of maintenance don't know why a cable broke off, that means it will fall down.

On Nov. 6, one of the four main cables atop the same tower snapped. The probability of losing Arecibo entirely began to sink in.

Méndez: The big issue in all the meetings was that the NSF was holding everything up. They were so scared of the observatory collapsing at any moment that they imposed strong restrictions about repairs.

The impression that I got from the staff of the observatory was that they had the engineers — we could start anytime. They were eager to start repairs.

But NSF said, no, don't risk life. And I was — many people were mad at this decision. And you have to see the point of the NSF that this was a risky operation and people might lose their life there if something happens.

But we know that people were willing to risk their life.

On Nov. 20, 2020, NSF announced that, after consulting with engineering firms, it

Junellie González Quiles (@JunellieG):
As part of the Arecibo Space Academy for high school students, we got to tour the Arecibo Observatory. It's where scientist Junellie was born and I will always treasure that.
8:28 AM · Nov 20, 2020

had determined that safe repairs were impossible and that it would close Arecibo in a "controlled decommissioning."

Before that could happen, on Dec. 1, the rest of the cables atop the southeast tower snapped and the 900-ton platform collapsed, swinging across the dish and smashing through the reflectors in the valley below.

The crumpled remains of Arecibo's receiving platform lie strewn across the valley below in this photo taken one week after its collapse. NSF is consulting with Puerto Rican historic preservation authorities to identify objects of scientific and cultural value to be preserved and displayed onsite or in museums. MICHELLE NEGRON, NATIONAL SCIENCE FOUNDATION

Méndez: I thought that I would never see something like that. I thought that the observatory would outlast my life.

Altschuler: It was horrible. I tell you, when I heard about it, I cried. Honestly, I tell you, I shed tears. And this was a long time ago, but I spent 17 years of my life there. And my wife and I embraced and we just cried a bit.

It wasn't just a telescope somewhere on top of a mountain, you know — we lived there. It was our home, it was a family. Before the problems, you know — even during the problems — people felt like they belonged to the Arecibo Observatory, and they were proud of it.

Pantoja: This grieving thing is a weird thing. I haven't been back to the observatory. But when that time comes, that is gonna be hard. I did that drive so many times. Just before you arrive to the observatory, you're going through this beautiful path in the mountains, and you get a peek of it. Because it's high. That's what you would see: the towers and everything. And I can imagine going there and then not seeing it.

I think that's going to be the hard part that I've been thinking about — that I'll feel all the things that I'm missing, that I will miss, it will hit me concretely there.

Arianna Colón Cesaní, undergraduate student at UPR, Mayagüez: I saw myself coming back to Puerto Rico — after I finished my graduate studies in the United States, and then, you know, making a happy living over here. When Arecibo crashed down, it kind of put it in perspective, like, "Wait, I might not be able to come back at all, I might have to go elsewhere." And then that's it, because there are no other options over here.

FIGHTING FOR REBIRTH

When NSF announced its decision to decommission Arecibo, it emphasized that outreach and education activities would continue onsite. But as researchers around the world mourned the loss of Arecibo on overflowing Zoom calls, a movement to replace the telescope itself began to emerge.

Lebron: What is the scientific plan for the facility that they want to put there? I think that NSF hasn't said that clearly yet. I would like to know because I am a scientist. Now we have some call from NSF that they want to strengthen our education and cultural things, but — I am a scientist! I am a scientist! Yeah, I'm happy with the cultural, I'm happy with the education, I am happy at university. But where is my science?

Pantoja: If you're trying to mitigate that big loss with outreach, I mean, it wouldn't be enough. You would also want some people to be able to return to their communities to pursue a career in astronomy.

In January 2021, a white paper began circulating, proposing a next-generation Arecibo telescope. Instead of one giant dish, it would comprise a networked array of smaller dishes and offer twice the sensitivity of the original, with a field of view 500 times larger and an expanded frequency range. In April, NSF convened a workshop to discuss future options for Arecibo.

Méndez: When I read the white paper, I was blown over. The night after, I didn't sleep well. I was like, "Wow, if this becomes a reality, what an instrument we will have."

And I think that was probably what scientists in the 1960s felt when talking about constructing the original Arecibo telescope, that it's a sci-fi machine with unbelievable sensitivity. And of all the things you think that they were planning to do — like study the ionosphere, like the first maps of Venus — nobody predicted that they would detect exoplanets or all the pulsars that helped to confirm relativity.

I want to see something majestic there that even the original observatory would be proud of.

Mark Zastrow *is senior editor of* Astronomy.

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

Jupiter (the bright object left of center) and Saturn (left of Jupiter) blaze in the sky above Castle Gresti in Sicily. This shot was taken in June 2020, a month before both giant planets reached opposition. DARIO GIANNOBILE

AUGUST 2021

See Jupiter and Saturn at opposition

On early August evenings, you'll find three rocky planets in the sky: Venus, Mars, and Mercury. Venus is easy to spot, so use it as a guide to find the other two, which are more challenging in twilight. Overnight there's a planet spectacular starring Saturn and Jupiter, both of which reach opposition this month. Jupiter provides some unique satellite events not to be missed if you have a telescope. Binocular viewers can track down distant giants Uranus and Neptune in the morning sky.

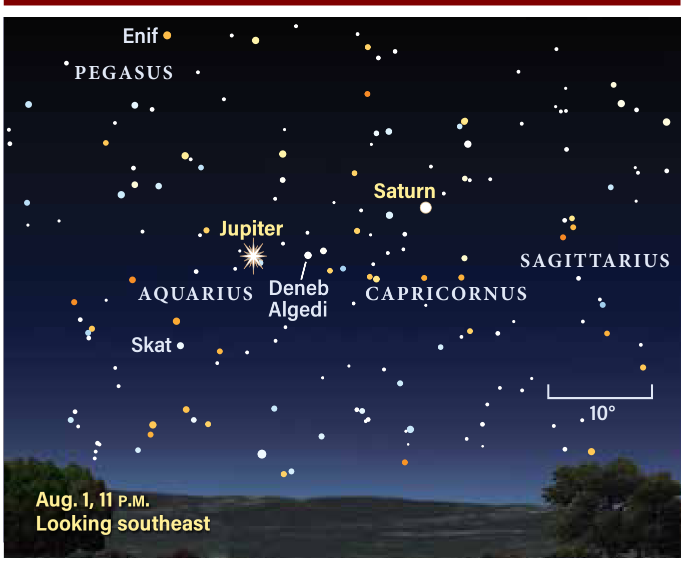
Brilliant **Venus** dominates the western sky this month. It glows at magnitude –3.9 in early August and is 8° high in the west 45 minutes after sunset, easy to spot as twilight descends. The planet roughly maintains this position as it slides along the ecliptic through Leo and Virgo, moving southwest. Venus crosses the celestial equator by Aug. 17 and continues to more southerly declinations. While its elongation from the Sun increases from 33° to 40° this month, the planet doesn't gain altitude for Northern Hemisphere observers.

On Aug. 10, a thin three-day old crescent Moon pairs elegantly with Venus. Note the earthshine illuminating the dark portion of our satellite. Set against the deep blue twilight, this is a memorable scene. By Aug. 13, Venus appears to have a moon of its own: 4th-magnitude Beta (β) Virginis is located just 8' to its southwest. Use binoculars to pick up the dim star. By August's end, Venus and Virgo's brightest star, Spica, hang low in the west, less than 7° apart. Venus, now magnitude –4, outshines 1st-magnitude Spica.

Venus' sheer brilliance makes details more difficult to view when the sky is dark. Try very early in twilight or even before sunset (never point your telescope toward the Sun). Venus is 82 percent lit and 13" wide on Aug. 1. By month's end, the phase shrinks to 73 percent lit and the planet spans 15".

Much dimmer magnitude 1.8 **Mars** is located 11° west (lower right) of Venus on Aug. 1. Mars also stands 2° from magnitude 1.4 Regulus. Both are

Saturn rides high in the southeast



Saturn reaches opposition Aug. 1/2 (depending on your time zone). The planet is visible all night, followed closely by Jupiter. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

SATURN reaches opposition early on Aug. 2. **JUPITER** follows two and a half weeks later, reaching opposition the evening of Aug. 19.

a challenging 5° high in the west 30 minutes after sunset. Try using binoculars to spot them; you'll need a clear horizon. They set about an hour after the Sun.

Mars is a few months away from solar conjunction and gradually becoming more difficult to observe. Over the next few days, Regulus quickly drops out of view and the Red Planet slides eastward across Leo. Your last view of Mars could be Aug. 9, when a slender two-day-old Moon is visible for about an hour after sunset, with Mars 3.5° to its south.

Mercury makes a brief, low appearance this month. Following superior conjunction Aug. 1, it moves into the evening sky, nestled in twilight. Lucky observers with a clear western horizon may catch it Aug. 9 — the same day the Moon and Mars are close. Mercury lies 9° west of the Moon and sets 30 minutes after the Sun. At magnitude –1.1, you may catch it in binoculars 15 minutes after sunset, now 2° above the horizon.

Mercury extends its separation from the Sun each day, but for Northern Hemisphere observers, it doesn't gain altitude. It also slowly fades. Try to catch Mercury and Mars in an extremely close conjunction Aug. 18. Twenty minutes after sunset, Mercury stands

— Continued on page 38

RISING MOON | A view of the bay

PROMINENTLY LOCATED in the northwest quadrant of the lunar face is the Bay of Rainbows, Sinus Iridum. And what a sight on the evening of the 17th: A striking semicircular arc of mountains greets the Sun!

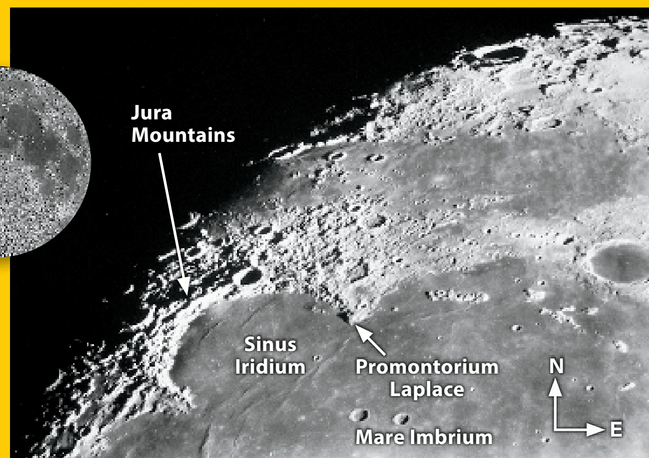
The leading peak, Promontorium (Cape) Laplace, casts a long shadow across the undulating lavas of the bay. Watch it shorten over a few hours as the Sun continues to rise, painting its light slowly down the flanks of the westernmost peaks.

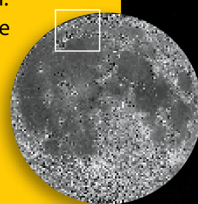
The highest points on the dark side of the terminator will flicker in and out, changing color in the same way Sirius twinkles due to Earth's atmospheric turbulence. Perhaps this is why it was named the Bay of Rainbows.

Well defined by their shadows on the 17th, the long wrinkle ridges stretching south disappear by the 19th under a higher Sun. The Jura Mountains that form the arc of Iridum separate the bright highland material to the north from the darker Mare Imbrium to the south.

It was here eight years ago that China landed their Yutu (Jade Rabbit) rover. Scientists deduced that the surface in this region is indeed volcanic basalt representative of the Moon's upper mantle, a full billion years younger than the 4-billion-year-old samples returned by Apollo astronauts.

Bay of Rainbows

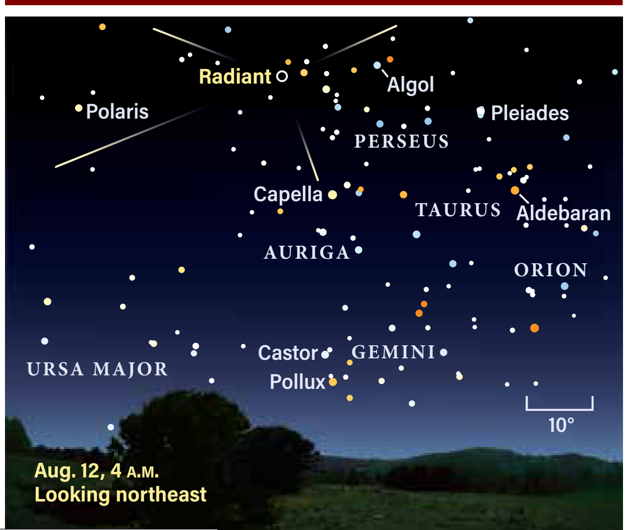




On Aug. 18, the Bay of Rainbows will appear similar to this image from the *Consolidated Lunar Atlas.* CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Morning show

Perseid meteor shower



Many bright Perseids leave a fluorescent trail called a persistent train. Longer streaks typically lie some distance from the radiant, so center your view 40° to 60° away from this point.

PERSEID METEORS
Active dates: July 17–Aug. 24
Peak: Aug. 12
Moon at peak: Waxing crescent
Maximum rate at peak: 110 meteors/hour

ONE OF THE YEAR'S BEST showers, the Perseids, occurs in August. This year, conditions are very favorable with no Moon after midnight. The Perseids peak Aug. 12 during the day for U.S. observers; the mornings of the 12th and 13th should provide good rates. If your weather is poor, try the 10th and 11th as well.

On Aug. 12, a four-day-old Moon sets soon after 10:30 P.M. local time, offering ideal dark sky conditions for meteor observing. The radiant in Perseus rises to around 60° in the hour before dawn, attenuating the listed zenithal hourly rate (which occurs when the radiant is at 90° elevation) of 110 meteors per hour by about 15 percent. This converts to an average of one meteor per minute in the predawn hours.

Perseid meteors are the result of debris left by Comet 109P/Swift-Tuttle. The shower was widely known by the 1830s but certainly had been active before that date.

STAR DOME

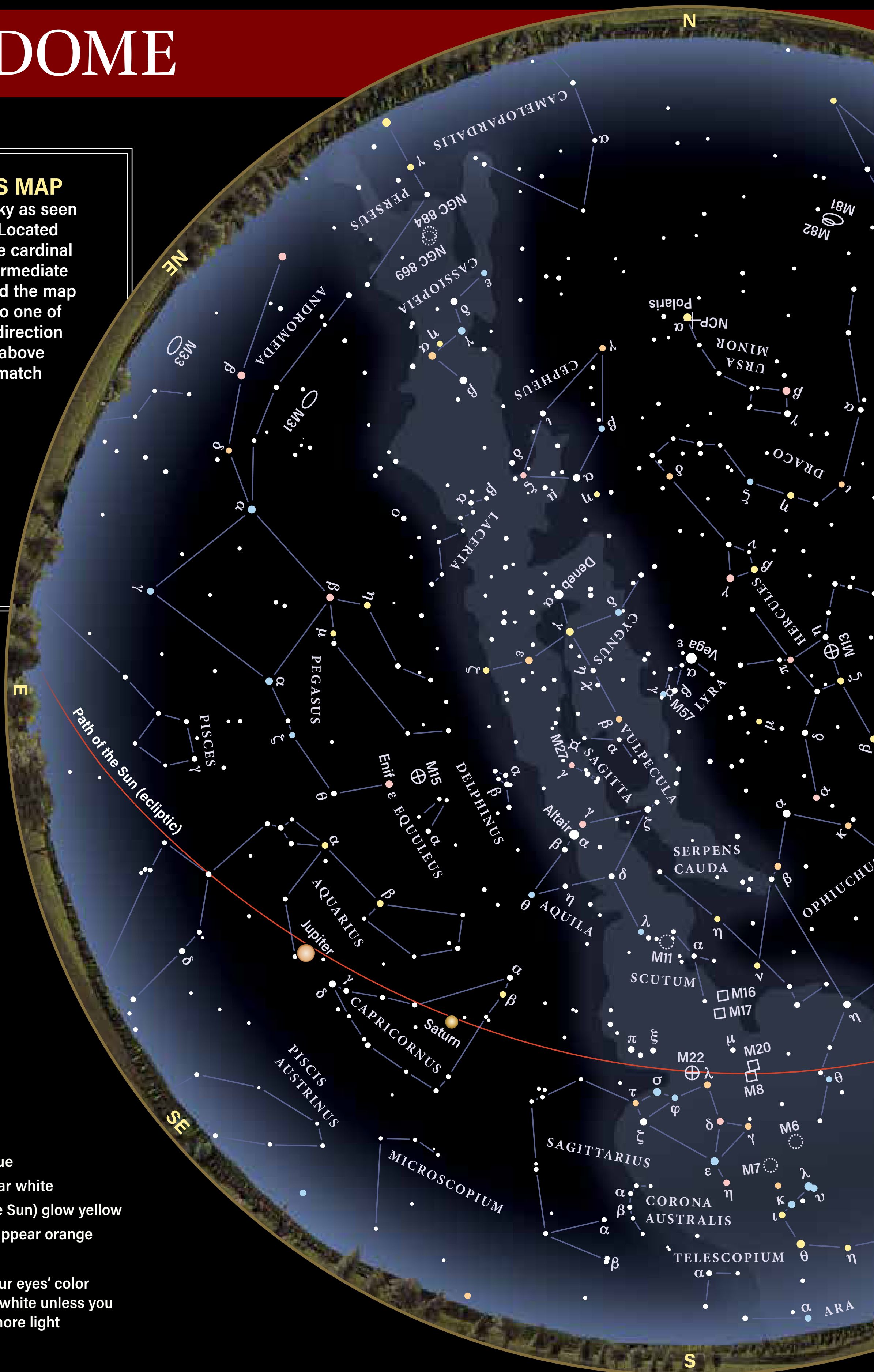
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

11 P.M. August 1
10 P.M. August 15
9 P.M. August 31

Planets are shown at midmonth



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

AUGUST 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 Mercury is in superior conjunction, 10 A.M. EDT

2 Saturn is at opposition, 2 A.M. EDT

The Moon is at apogee (251,289 miles from Earth), 3:35 A.M. EDT

4 Asteroid Juno is stationary, midnight EDT

8 New Moon occurs at 9:50 A.M. EDT

9 The Moon passes 4° north of Mars, 9 P.M. EDT

11 The Moon passes 4° north of Venus, 3 A.M. EDT

Mercury passes 1.2° north of Regulus, 2 P.M. EDT

12 Perseid meteor shower peaks

15 First Quarter Moon occurs at 11:20 A.M. EDT

17 The Moon is at perigee (229,363 miles from Earth), 5:16 A.M. EDT

18 Mercury passes 0.08° south of Mars, midnight EDT

19 Asteroid Ariadne is at opposition, 3 A.M. EDT

Jupiter is at opposition, 8 P.M. EDT

Uranus is stationary, midnight EDT

20 The Moon passes 4° south of Saturn, 6 P.M. EDT

22 The Moon passes 4° south of Jupiter, 1 A.M. EDT

Full Moon occurs at 8:02 A.M. EDT

23 The Moon passes 4° south of Neptune, 10 P.M. EDT

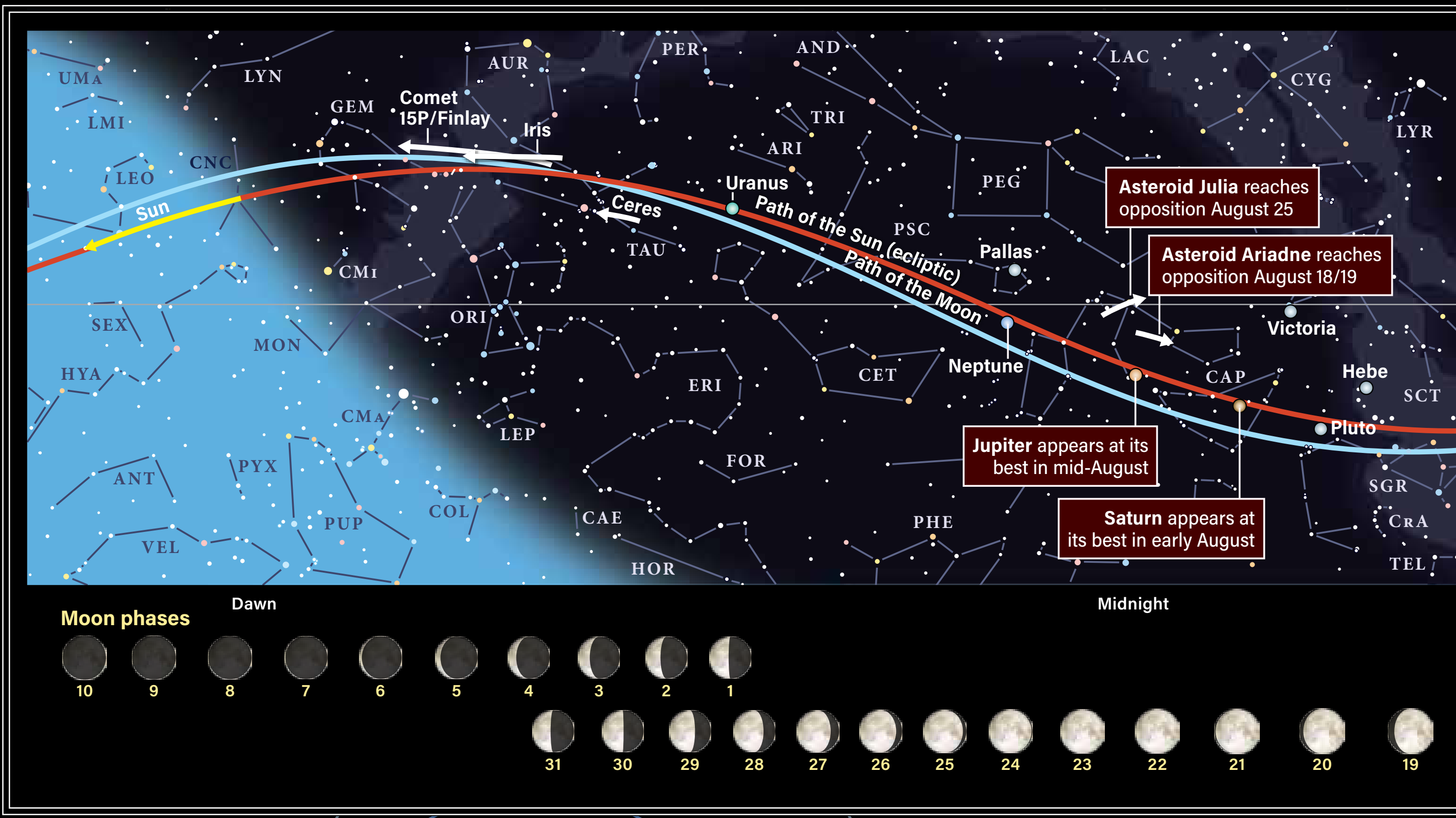
25 Asteroid Julia is at opposition, 7 A.M. EDT

28 The Moon passes 1.5° south of Uranus, 5 A.M. EDT

29 The Moon is at apogee (251,096 miles from Earth), 10:22 P.M. EDT

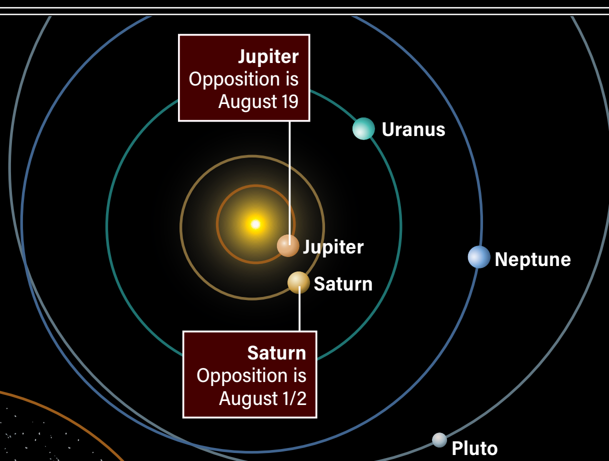
30 Last Quarter Moon occurs at 3:13 A.M. EDT

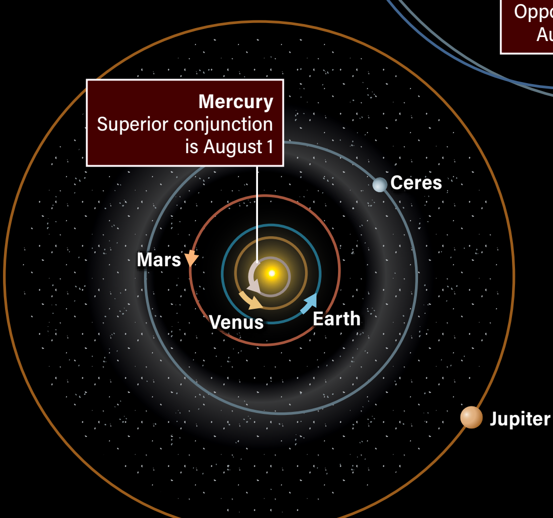
PATHS OF THE PLANETS



THE PLANETS IN THEIR ORBITS

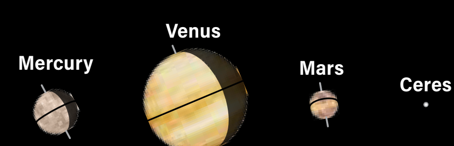
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

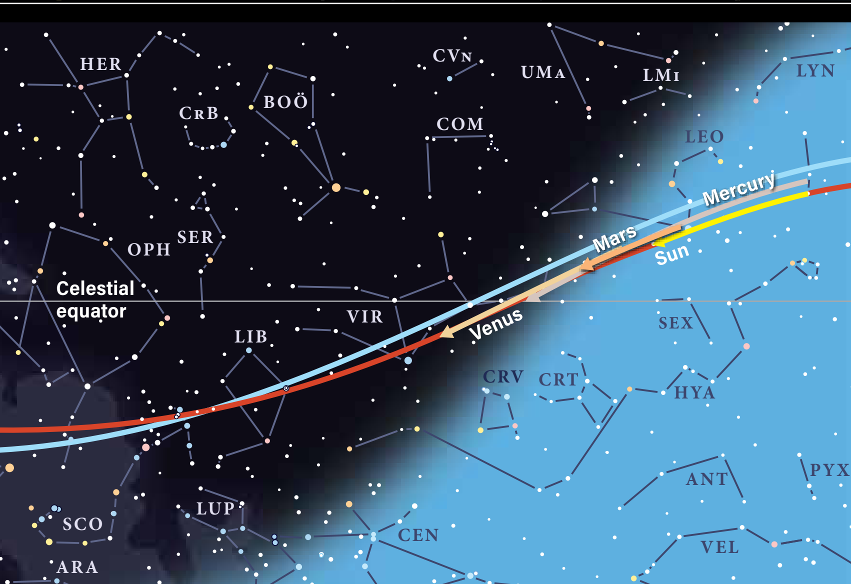
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Aug. 31	Aug. 15
Magnitude	–0.1	–4.0
Angular size	5.8"	13.6"
Illumination	75%	78%
Distance (AU) from Earth	1.159	1.226
Distance (AU) from Sun	0.462	0.724
Right ascension (2000.0)	12h02.0m	11h55.0m
Declination (2000.0)	–0°53'	1°23'

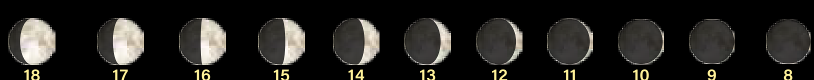
AUGUST 2021

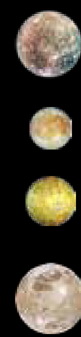
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.



Early evening

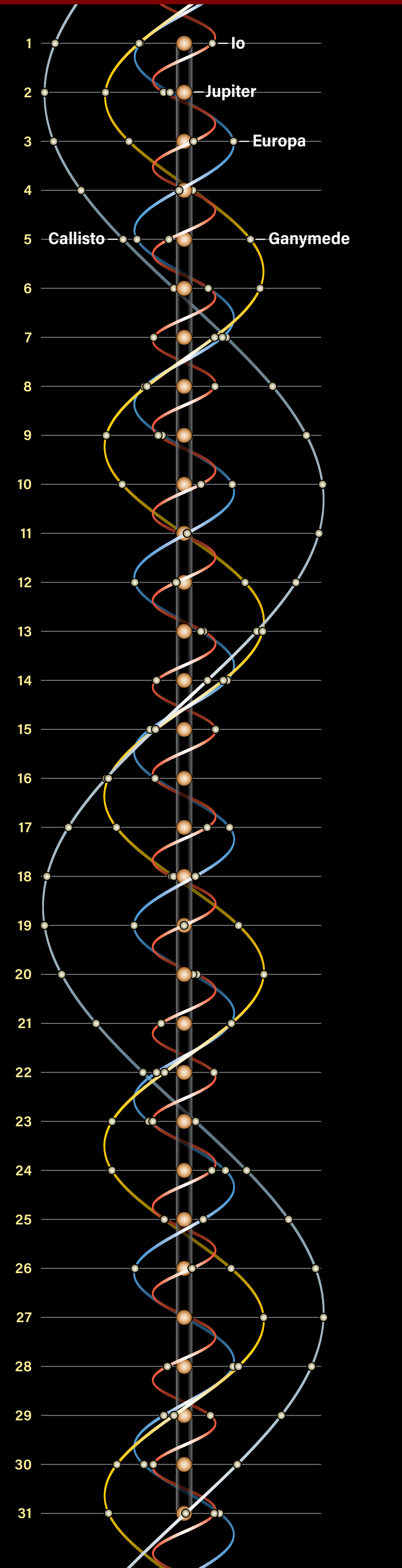
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.



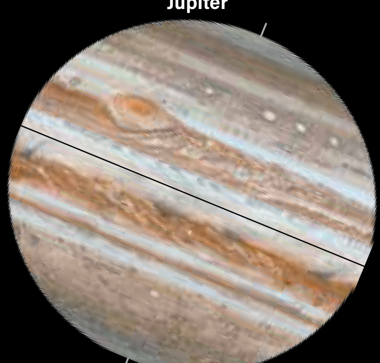


JUPITER'S MOONS

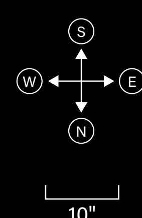
Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.



Jupiter



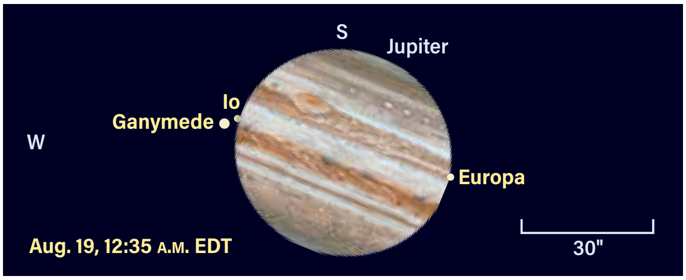
Saturn



MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Aug. 1	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15
1.8	8.9	–2.9	0.2	5.8	7.7	15.0
3.7"	0.5"	49.1"	18.6"	3.6"	2.4"	0.1"
99%	97%	100%	100%	100%	100%	100%
2.557	2.854	4.017	8.959	19.582	29.043	33.440
1.664	2.829	5.026	9.948	19.742	29.923	34.341
10h14.0m	4h12.1m	22h00.7m	20h46.4m	2h48.6m	23h33.4m	19h47.4m
12°07'	14°38'	–13°25'	–18°47'	15°47'	–4°08'	–22°47'

SKY THIS MONTH — *Continued from page 33*

Poised for action



A series of several exciting events occurs overnight on Aug. 18/19, starring Io, Europa, and Ganymede. Callisto lies farther to the planet's west.

4° high and shines at magnitude –0.6. Mars stands 7' east of Mercury. Dim Mars is tough to spot, but follow Mercury as the sky darkens for a glimpse of the Red Planet. Mercury remains low and dims to magnitude 0 at the end of August, when it stands 3.5° high in the west 30 minutes after sunset.

Saturn reaches opposition at 2 A.M. EDT Aug. 2. Rising in the southeast as the Sun sets, you'll find the ringed planet 15° high by 10 P.M. local time. It reaches 30° altitude by Aug. 31 at the same time. Saturn is easy to spot among the faint stars of Capricornus the Sea Goat, outshining everything in this region. The planet starts August at magnitude 0 but quickly dims to 0.2 for the rest of the month.

Like all outer planets, Saturn is best viewed near the meridian; at opposition, this is around local midnight (1 A.M. for locations using daylight time). Any backyard telescope will reveal its 19"-wide disk, encircled by the magnificent ring system spanning 42" by 13". Details of Saturn's subtle atmospheric belts are best seen by allowing your eyes to catch fleeting periods of good seeing. Saturn's polar diameter spans 17" and the rings' diminishing angle to our line of sight (now 18°) reveals the south polar region.

Saturn's brightest moon, Titan, orbits every few weeks. You'll find it north of the planet Aug. 3 and 19, and south of the planet Aug. 11 and 26/27.

Tenth-magnitude Tethys, Dione, and Rhea hover closer to the rings, changing relative positions hourly. Fainter magnitude 12 Enceladus orbits a few arcseconds from the rings' bright edge. On Aug. 2, this moon appears to gain a twin when a field star of similar brightness lies close to it on the east side of the rings. Just a few minutes of observation between sunset and local midnight will show their relative positions changing. The moon and star appear closest (3" apart) around midnight EDT on the 2nd. If you miss it, try again Aug. 8, when another field star passes 12" south of the moon.

Iapetus reaches eastern elongation nearly 9' due east of Saturn on Aug. 12, shining close to magnitude 12. It then moves back toward Saturn, brightening by 1 magnitude and reaching inferior conjunction 50" from Saturn on Aug. 31.

Jupiter rises an hour after Saturn and reaches opposition Aug. 19. Located in southern Aquarius, Jupiter glows a brilliant magnitude –2.8 Aug. 1 and brightens to –2.9 by midmonth. Its retrograde track carries it into Capricornus on Aug. 18. You'll find Jupiter 5° north of the Full Moon on Aug. 21.

Jupiter is a wonderful object through a telescope. Its disk spans its widest for the year at 49" and the planet lies 4 astronomical units (AU) from Earth (1 AU is the average Earth-Sun distance). Any telescope will reveal fine details in its atmosphere, which is best seen when the planet is near your local meridian in the hour after midnight. Jupiter stands 36° high at 1 A.M. local time; it is somewhat higher for observers

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)
Venus (west)
Mars (west)
Jupiter (east)
Saturn (southeast)
Neptune (east)

MIDNIGHT
Jupiter (south)
Saturn (south)
Uranus (east)
Neptune (southeast)

MORNING SKY
Jupiter (southwest)
Saturn (southwest)
Uranus (southeast)
Neptune (southwest)

COMET SEARCH | Star-studded path

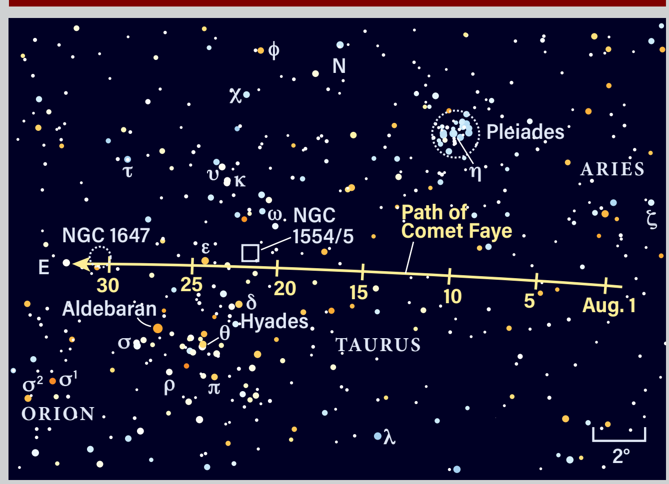
THE CLOSER on a short summer's night should be Comet 4P/Faye. A 6-inch scope under country skies will pick up the 10th-magnitude fuzz approaching the midpoint of the Pleiades and Hyades star clusters in Taurus.

You may not see it at first with low power, so try about 100x. The stubby, ill-defined tail drifts out of the eyepiece, followed by the sharper flank, which faces the solar wind. Compare it to globular star cluster M72 in Aquarius.

Barely a couple of miles wide, Faye hadn't yet been recovered in early April, when its distance was 2.2 AU. By contrast, Comet C/2017 K2 — expected to rank in the top three comets for the entirety of 2022–2023 — was discovered four years ago when it was still out at 16 AU.

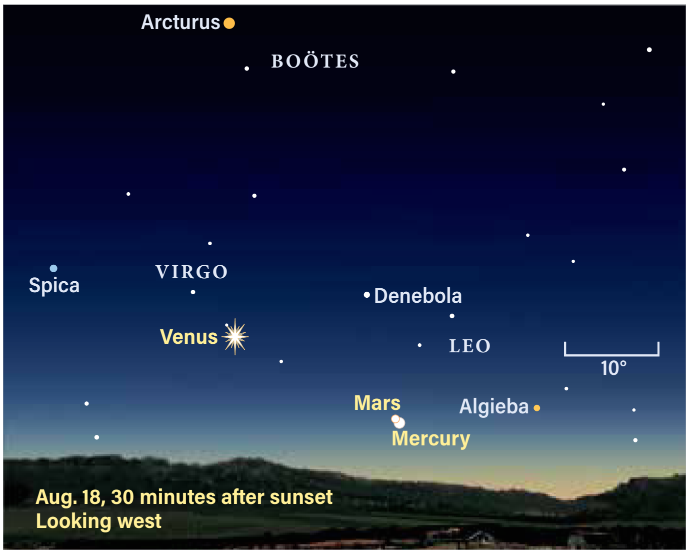
Hervé Faye first saw 4P in 1843, when suburban Paris had few lights at night. Returning every 7.6 years, the comet won't give us another good look until 2036.

Comet 4P/Faye



The moonless window for observing Comet Faye runs from Aug. 3 to 18.

Mercury and Mars mingle



Mercury and Mars appear separated by a mere 7' shortly after sunset on Aug. 18. Use brighter Mercury as a signpost to find the dimmer Red Planet.

in southern states and lower for those in northern ones.

It's the best time of the year to see the two dark belts straddling the equator, as well as the associated plumes and festoons of more gently shaded features. These sights move quickly with Jupiter's rotation period, which ranges from 9 hours 50 minutes to 9 hours 55 minutes.

Galilean moons Io, Europa, Ganymede and Callisto are easy to track in small scopes. Io swaps sides — from east to west — night after night. The others do the same over longer periods. Larger scopes (8 inches or more) may reveal the disks of Ganymede and Callisto around opposition if seeing conditions permit. They span 1.8" and 1.7", respectively.

Special this year are mutual events of the satellites themselves, where one moon eclipses or occults another. This occurs when their orbital planes align exactly with our line of sight. Four events are visible from the continental U.S.: two overnight on Aug. 8/9, one early on Aug. 16, and one final event overnight on Aug. 18/19. Under typical seeing conditions, most observers will detect a blending of two moons during an occultation or a dimming of one moon during an eclipse. Visit www.Astronomy.com/skythisweek for details on each event. There are many other transits and occultations of individual moons with Jupiter throughout the month.

Neptune rises two hours after sunset in early August, and is 20° high in the east by local midnight. It glows at magnitude 7.7 — within reach of binoculars and appearing as a dim star. You'll find it just over 5° east of 4th-magnitude Phi (ϕ) Aquarii and due south of the Circlet in Pisces. A telescope under high power and good seeing conditions reveals its bluish 2"-wide disk. On Aug. 25, Neptune sits midway between two brighter (magnitude 6.5 and 6.9) field stars. During August, Neptune drifts westward (retrograde), moving closer to Phi. It reaches opposition next month.

Uranus lies in a dim part of southern Aries, rising soon after local midnight on Aug. 1 and beginning its retrograde motion after reaching its stationary point at midnight EDT Aug. 19. The planet is best viewed in the hours before dawn. Uranus hasn't been this far north (declination 16°) for nearly 60 years. It's an easy binocular object at magnitude 5.8. Look for it as the apex of an equilateral triangle with Omicron (ο) and Sigma (σ) Arietis — magnitude 5.8 and 5.5, respectively — forming the base. A telescope will reveal Uranus' planetary status as a 4"-wide greenish-blue disk, distinctly not starlike. Uranus stands 5° east of the waning Moon half an hour before sunrise Aug. 1. The Moon returns to the vicinity Aug. 28. This time, Uranus stands 1.8° northwest of our satellite half an hour before sunrise, with Sigma Ari less than 1° from the Moon's northern limb.

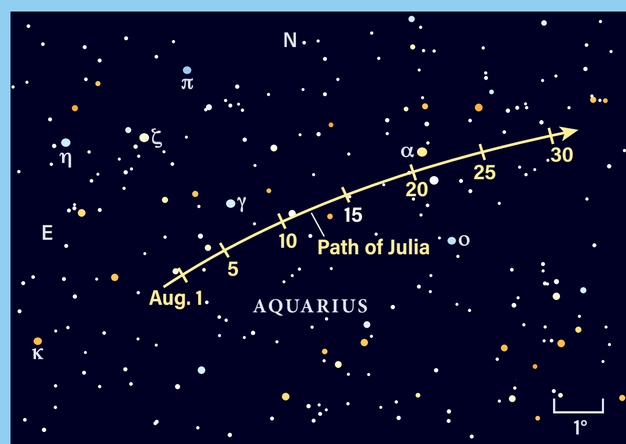
LOCATING ASTEROIDS | Go with the flow

ABOVE THE BLAZING BEACON of Jupiter (to the planet's northeast), our eyes alight on a tight grouping of 4th-magnitude stars nicknamed the Water Jar asterism. In larger cities, you may need binoculars to pick it up, with 3rd-magnitude Alpha (α) Aquarii leading the pack. Together they form a recognizable backdrop that helps us home in on our target.

Reaching a peak brightness of magnitude 8.9 on its opposition date, Aug. 24, 89 Julia will require a 60mm scope at 80x to spy it. Thankfully, we are far from the profusion of Milky Way stars in the background that might overwhelm us. Nights to note are the 3rd and 4th, as well as the 19th and 20th; these pairs of nights are when the anchoring field stars allow you to see Julia's small shift at the bookends of a two-hour observing session. Avoid the nights of Aug. 21 and 22, when the Moon's bright glare is nearby.

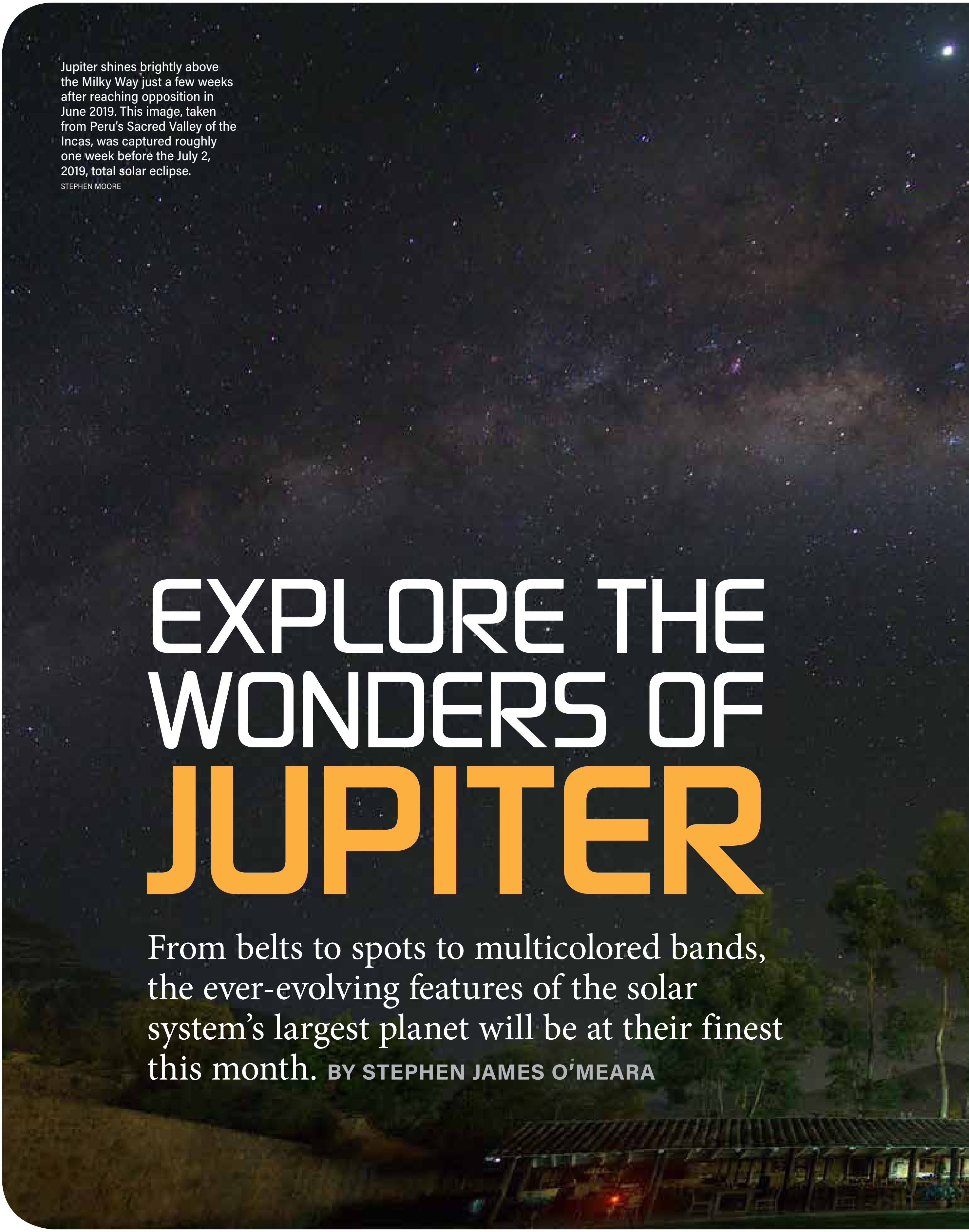
Plying the main belt between Mars and Jupiter, this small world was named after Saint Julia. Édouard Stephan, who discovered the marvelous galaxy group we continue to call Stephan's Quintet, first spotted the asteroid in August 1866.

By the Water Jar



Asteroid Julia passes quickly by Aquarius' Water Jar asterism, which comprises Gamma (γ), Zeta (ζ), Eta (η), and Pi (π) Aquarii.

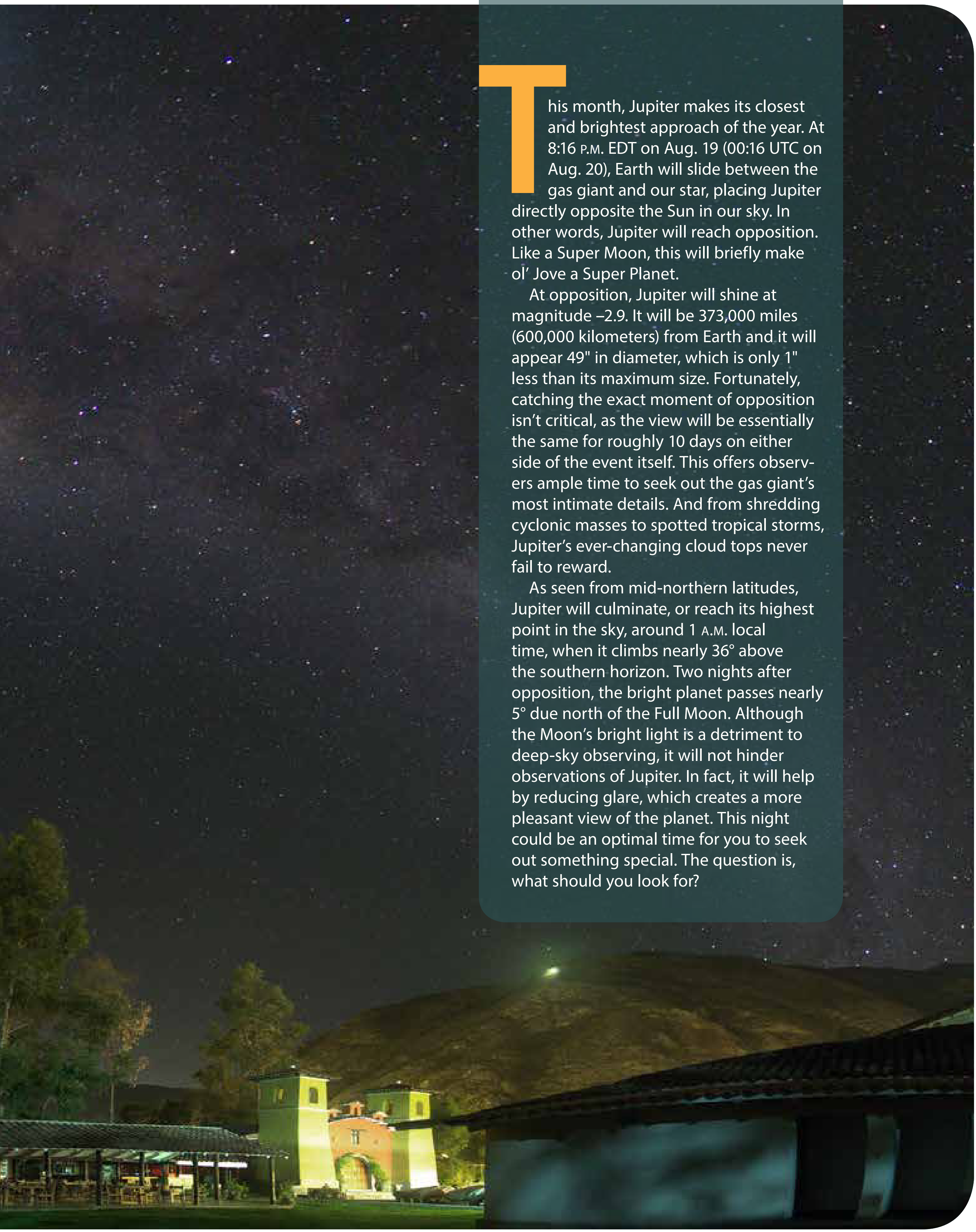
Martin Ratcliffe *is a planetarium professional and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*



Jupiter shines brightly above the Milky Way just a few weeks after reaching opposition in June 2019. This image, taken from Peru's Sacred Valley of the Incas, was captured roughly one week before the July 2, 2019, total solar eclipse.
STEPHEN MOORE

EXPLORE THE WONDERS OF JUPITER

From belts to spots to multicolored bands, the ever-evolving features of the solar system's largest planet will be at their finest this month. **BY STEPHEN JAMES O'MEARA**



This month, Jupiter makes its closest and brightest approach of the year. At 8:16 P.M. EDT on Aug. 19 (00:16 UTC on Aug. 20), Earth will slide between the gas giant and our star, placing Jupiter directly opposite the Sun in our sky. In other words, Jupiter will reach opposition. Like a Super Moon, this will briefly make ol' Jove a Super Planet.

At opposition, Jupiter will shine at magnitude –2.9. It will be 373,000 miles (600,000 kilometers) from Earth and it will appear 49" in diameter, which is only 1" less than its maximum size. Fortunately, catching the exact moment of opposition isn't critical, as the view will be essentially the same for roughly 10 days on either side of the event itself. This offers observers ample time to seek out the gas giant's most intimate details. And from shredding cyclonic masses to spotted tropical storms, Jupiter's ever-changing cloud tops never fail to reward.

As seen from mid-northern latitudes, Jupiter will culminate, or reach its highest point in the sky, around 1 A.M. local time, when it climbs nearly 36° above the southern horizon. Two nights after opposition, the bright planet passes nearly 5° due north of the Full Moon. Although the Moon's bright light is a detriment to deep-sky observing, it will not hinder observations of Jupiter. In fact, it will help by reducing glare, which creates a more pleasant view of the planet. This night could be an optimal time for you to seek out something special. The question is, what should you look for?

A red hook seems to be spinning off the Great Red Spot in this image captured by NASA's Juno spacecraft on Feb. 12, 2019. Note the intense orange color of the spot. A giant anticyclone, the Great Red Spot measures roughly 10,000 miles (16,000 km) across and some 100 to 200 miles (160 to 320 km) deep. It produces winds up to 270 mph (435 km/h) and has been swirling in Jupiter's clouds for at least 200 years. NASA/JPL-CALTECH/SWRI/MSSS

An awe-inspiring world

At a glance, Jupiter's entire face is covered with reddish brown belts and bright zones of various hues, all of which run parallel to the planet's equator. Careful observations during the most pristine moments of steady atmospheric seeing, however, reveal even finer details. These include bright and dark spots, looping festoons, and other shapes that, despite their solid appearance, are in a state of perpetual change. Such shapeshifting is a result of powerful jet streams whipping both west to east (prograde; in the direction of rotation) and east to west (retrograde; opposite the direction of rotation) across the planet.

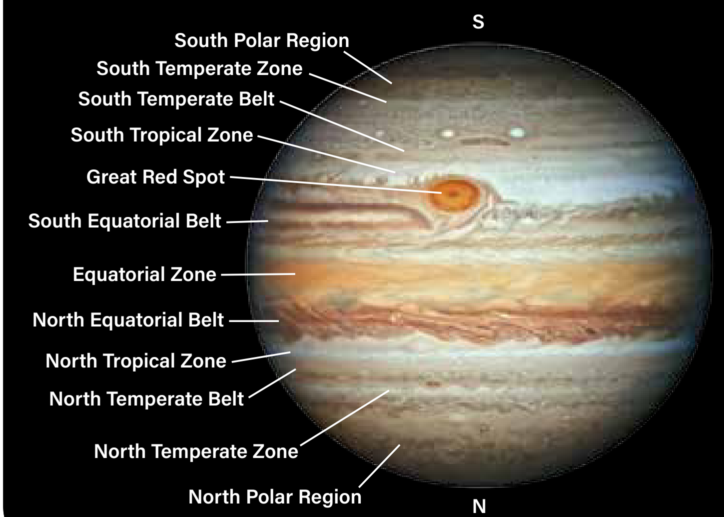
These jets separate Jupiter's bands, and the instabilities they introduce can spur atmospheric waves and cyclonic storms, as well as eruptive plumes that distort the flow and color of the planet's zones. Trying to predict when such events might occur is a bit like forecasting storms on Earth, where one analyzes historical and current trends to attempt to presage future activity.

So, let's start by exploring some past events on Jupiter to see if they'll tell us anything about the future. What follows is based, in part, on information gleaned from reports by Glen Orton and Thomas Momary of NASA's Jet Propulsion Laboratory and John Rogers of the British Astronomical Association. Remember, though, that Jupiter is a dynamic world and it's always ready to surprise.

The Great Red Spot

The mystifying colossus that is the Great Red Spot (GRS) is the largest and most enduring storm in the solar system. And since 2017, the development of particularly intense color within the storm (the likes of which hasn't been seen for decades) has captivated observers — alongside its slivers of red flakes, blades, and hooks spinning off the Spot like ice skaters playing Crack the Whip. Some of these events were obvious enough to be spied through a 3-inch refractor at 300x.

JUPITER CLOUD FEATURES



Jupiter's dark belts, bright zones, polar regions, and Great Red Spot are shown here as they appear through a simple inverting scope. NASA/JPL/SPACE SCIENCE INSTITUTE

Jupiter, our solar system's largest world, shows more detail through a backyard scope than any other planet — and those details are best seen during opposition. This image from Juno, however, captures an up-close view of the mesmerizing turbulence in the gas giant's southern hemisphere. South is up, although the angle of this shot is deceiving. NASA/JPL-CALTECH/SWRI/MSSS/KEVIN M. GILL

Given that the GRS had been shrinking in size at an accelerated rate since 2012, concerns arose that the flaking episodes signaled its demise was near.

However, this may not be the case. The Spot's apparent disintegration could actually be a visual illusion. Velocity measurements of the flakes have shown that much of the matter is not being flung out, as it appears to the eye. Instead, the material is simply flowing into or around the Spot. Recent observations even suggest the GRS's shrinking trend has ceased and now may be growing — from 12.1° in apparent length in June 2020 to 14.0° in late October 2020. A study published March 16, 2020, in *Nature Physics* also found that, despite the shift in surface area, the Great Red Spot's thickness has probably remained constant over the past four decades or so, casting further doubts on its impending death.

These flaking events could continue through opposition, too. Either way, you might want to time your Jupiter observing sessions to track the Spot's passage across the planet's meridian, monitoring whether the storm's apparent size grows or shrinks over time. Also pay attention to the GRS's color, which has shown signs of fading recently.

BOTTOM LEFT: NASA/ESA/STSCI/A. SIMON (GODDARD SPACE FLIGHT CENTER)/M.H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY)/OPAL TEAM

Taken in ultraviolet, visible, and near-infrared light, this Hubble Space Telescope image shows Oval BA in the throes of changing color above the Great Red Spot on Aug. 25, 2020.

Clyde's Spot is the small white oval near the middle of this image of Jupiter's cloud tops taken by the Juno spacecraft in June 2020. NASA/JPL-CALTECH/SWRI/MSSS; PROCESSING BY KEVIN M. GILL

The Little Red Spot

Observers should also keep an eye out for Jupiter's long-enduring Oval BA, which formed in 2000 in the planet's South Temperate Belt through the collision and merger of three smaller spots. Oval BA started off as white. But it began to redden in late 2005, leading to the catchy moniker the Little Red Spot (or Red Spot Jr.).

Then, in 2018, Oval BA's reddish hue started disappearing, ultimately returning the storm to a brilliant white color in 2019. By late 2020, however, the oval's core began to redden again. Astronomers believe atmospheric warming events are responsible for shifting the spot's color from white to red. So, if the region continues to warm, we might be treated to a revived Little Red Spot during this year's opposition.

Clyde's Spot

Early in the morning on May 31, 2020, amateur astronomer Clyde Foster of Centurion, South Africa, imaged a

This Hubble Space Telescope image taken Sept. 17, 2020, shows the brightening of the South Equatorial Belt's central region to the lower left of the Great Red Spot. Also visible to the Spot's right are the typical turbulent wakes that follow it. Note, too, the white storms curdling in both the North Equatorial Belt (at bottom) and the smoggy northern Equatorial Zone. NASA/ESA, A. SIMON (GODDARD SPACE FLIGHT CENTER) AND M.H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY)/OPAL TEAM.

curious new spot that had formed in Jupiter's southern hemisphere. He did so using a filter sensitive to certain wavelengths of light that are absorbed by methane gas, which is prevalent in Jupiter's atmosphere. The spot, however, was not visible in other images captured just hours earlier by astronomers based in Australia.

Only two days later, though, the Juno spacecraft snapped an image of what was quickly dubbed Clyde's Spot, a feature that turned out to be a plume of material erupting above the upper cloud layers of Jupiter's colorful atmosphere.

During this year's opposition, make sure to keep your eyes peeled for new eruptions, which occasionally occur around this latitude.

Equatorial Region

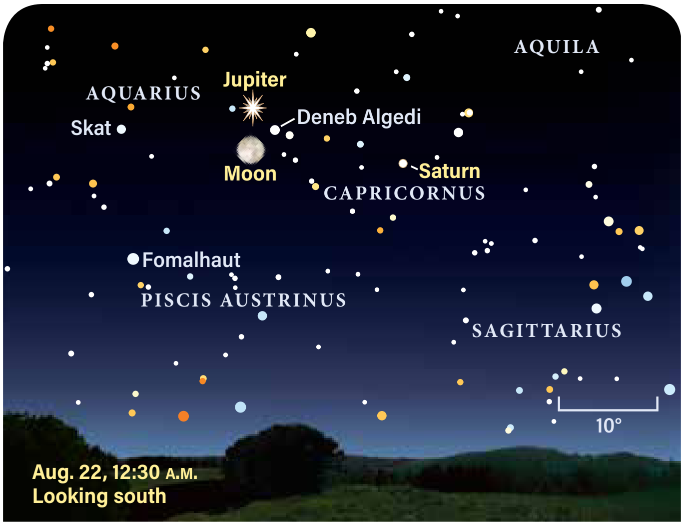
Jupiter's dark bands are known to expand, contract, or whiten for many months at a time. And occasionally, they fade away entirely. For example, in February 2020, a white storm erupted in the gas giant's South Equatorial Belt (SEB), ultimately spreading through the region to create a brighter zone that remains as of early 2021. However, it's hard to know what will happen in the area during this opposition.

The most dramatic event would be an SEB revival, where eruptions of bright white plumes signal a return to the SEB's standard brown appearance. SEB fade-and-return cycles can occur at intervals ranging from about three to 15 years. But then again, droughts between cycles can last as long as 36 years, with many intervening years of normal SEB activity. During this opposition, look for a possible color shift in the bright SEB zone, which has shown signs of yellowing in early 2021.

Every three to five years, Jupiter's North Equatorial Belt (NEB) expands to both the north and south. This expansion is associated with the dramatic and chaotic mixing of bright and dark material. After such an event occurred in 2017, the NEB ballooned again, as predicted, in May 2020.

First, a bright rift developed in the northern part of the NEB. It soon ejected dark material to both the north and south — perhaps as gas from the bright, ammonia-depleted plumes fell back into

A shadow from one of Jupiter's Galilean moons crosses the face of the gas giant on Aug. 18, 2020. DAMIAN PEACH/CHILESCOPE



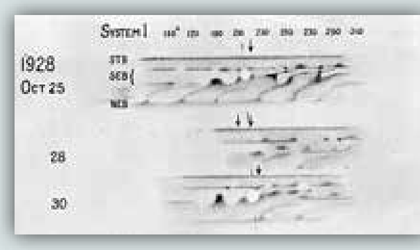
Jupiter reaches opposition at 8:16 P.M. EDT on Aug. 19. Less than three days later, the Full Moon appears 5° beneath the brilliant planet, which climbs above the east-southeast horizon at around sunset the night before. *ASTRONOMY*: ROEN KELLY

STRIP SKETCHES

Without question, today's amateur astrophotographers can snap outstanding images of Jupiter that almost rival those taken by the Hubble Space Telescope. These photos are of immense scientific value and their creators should be applauded. In mere moments, they can capture planetwide details that are impossible for visual astronomers to reproduce by hand, given the gas giant's fast rotation.

But visual astronomers can also record fantastic details on Jupiter by creating a strip sketch. This technique focuses on just one small section of the planet, allowing the observer to record as much detail as possible over the course of, say, 30 minutes to an hour or more. The method allows the sketcher to take advantage of crisp moments of perfect atmospheric seeing to record sub-arcsecond details in a small region of interest. It also allows them to track changes in that region over time, such as the rotation of the Great Red Spot, the movements of bright and dark features within a disturbance, or, as the illustration above shows, a revival of the South Equatorial Belt.

Just remember, make the sketches large so you don't limit the space between features, which are difficult to render at a smaller scale. For telescopes with apertures of 6 inches and smaller, a general magnification of 200x to 250x is sufficient. But if Earth's atmosphere is outstandingly steady, you can try pushing that limit to 75x per inch of aperture. Even if you make as few as four strip sketches of the same region during each apparition, you will create a general record of the changing aspects of this dynamic world. *—S.J.O.*



F.J. Hargreaves, a British master of the strip sketch, created these renderings of a South Equatorial Belt revival in October 1928. He observed the details through a 6½-inch reflector with a speculum mirror at 240x.


Jupiter and Saturn, with moons in tow, came within about 0.1° of each other during their conjunction in December 2020. Three of Jupiter's Galilean moons and several of Saturn's large satellites are visible. DAMIAN PEACH

the deeper (and darker) jovian atmosphere. Shortly after this activity, new dark elliptical features called barges, as well as white ovals, developed. While this action appears to be on the wane, it's unknown whether renewed activity might follow.

Since at least the late 19th century, Jupiter's Equatorial Zone (EZ) has often transformed from a brilliant white to an ochre/brown color. Today, we expect these so-called EZ disturbances roughly every eight years. They are heralded by an orangish hydrocarbon smog wrapping around the EZ and clearing out its high-altitude white clouds. A return of the disturbance — which astronomers initially predicted for the 2019 to 2021 period — began a bit early (mid-2018). And though it became one of the planet's most spectacular features in 2019, it has since mostly faded.

Aspects of the EZ disturbance have continued into early 2021, though. Namely, the EZ's northern section remains smoggy. Meanwhile, its southern section has brightened. Scientists are now interested in any changes to the EZ's color, whether it returns to its normal brightness or experiences a renewed darkening that might presage a truly disruptive event.

Northern tropical regions

On Aug. 18, 2020, a spectacular eruption occurred in Jupiter's North Tropical Belt (NTB) jet stream, producing an elaborate wake. Scientists had forecast that the eruption would occur in 2021, but it went off a year early. As the storm stretched out over time, amateurs discovered two more storms at the same latitude. All of them were superfast plumes with turbulent wakes that disrupted the entire width of the North Tropical Zone (NTZ), as well as the southern edge of the NTB.

While it's common for storms to pop up in this region every six years or so — often, multiple storms rage — it's unknown whether more events will continue to materialize during this year's opposition. While the individual plumes themselves are short-lived, color changes within the zone usually follow. And observations in early 2021 revealed that the NTZ has indeed become smoggy, mimicking the color of the northern EZ.

Galilean satellites

Several mutual events, such as occultations and eclipses, of Jupiter's satellites are visible during August. And three of them occur near opposition, when the planet and its Galilean moons look largest, offering you the best opportunity to study the satellites in detail. While most events require modest or large telescopes and high magnifications to see well, small telescope users can witness some of the events — especially partial occultations and the dimming or brightening effects present during greatest eclipses or pairings, respectively. To find out which mutual events are visible from your location in August, visit http://nsdb.imcce.fr/multisat/nsszph517he.htm and enter the code for the observatory nearest you from the available list.

Considering all the exciting possibilities for dramatic jovian events, August's opposition may prove to be one of the most memorable in recent years. The examples given here are but a few of the many potential sights that you might see at any time during Jupiter's apparition. Plus, who knows: Your amateur observations might even be key to helping professionals unlock the mysteries of this fascinating world.

Good luck, and may the wonders of Jupiter delight you!

Stephen James O'Meara *is a renowned planetary observer and author. His latest book is* Mars *by Reaktion Books.*

SKETCH (TOP LEFT): *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY*, VOL. 89, P.708, 1929

SEE SUMMER'S BEST

Messier objects

With these 20 objects, you can take a quick Messier run without breaking a sweat. BY MICHAEL E. BAKICH

The Messier marathon is an activity that's been popular with astronomy clubs since the 1980s. It's a test of endurance and skill to view each of the 109 deep-sky objects in French comet-hunter Charles Messier's catalog all in a single night.

The way that Messier objects are distributed across the sky means that there's only a short window from mid-March to early April where all objects are visible over the course of a single night.

But this year, if you missed out on the full marathon experience, you can at least keep your observational muscles fit by giving a mini-marathon a try.

In the spirit of my mini-Messier marathon for spring in the April 2021 issue (page 40), here is another list for the summer months: 20 great objects you can see between the time it gets dark and midnight.

For this observing sprint, start with the first object on the list below. It will be farthest west, so the following objects will set in order after it, giving you more time to observe them.

This summer, the Moon is New on July 9 and Aug. 8. So, your first observing window runs from the date you get this magazine until around July 12. After that, moonlight will interfere with your search until Last Quarter on July 31. Then, you'll have a second week-long window, where the sky will stay Moon-free until after midnight. As always, let your scope cool to the ambient temperature, savor each object, and have fun!

Our first object, the **Hercules Cluster** (M13), is one of the sky's top 10 brightest globular clusters, and one of only two on that list that are visible from the Northern Hemisphere. (The other, M5 in Serpens, is slightly brighter.) Under a dark sky, you'll spot this magnitude 5.8 object as a fuzzy "star" two-thirds of the way from Zeta (ζ) to Eta (η) Herculis.

With an apparent diameter of 16.6', M13's stars resolve even through a 3-inch telescope. Through an 8-inch or larger scope, try to spot the "propeller," a small, Y-shaped region of three dark lanes near M13's center.

Our next target, another fine globular, lies in Ophiuchus. Look for **M12** nearly 8° east-northeast of Yed Posterior (Epsilon [ε] Ophiuchi). It glows at magnitude 6.1 and measures 14.5' across. Through a 4-inch scope, a faint halo of stars surrounds a bright, compact core. Bump the aperture to 10 inches, and M12 will resolve into hundreds of stars.

Tarry in Ophiuchus for one more globular, **M10**. You'll find it 8° northeast of Zeta Ophiuchi. M10 glows at magnitude 6.6 and measures 15' across, half the Full Moon's diameter.

Through a 4-inch scope at low power, you'll first notice M10's bright core and then the faint halo around it. At 200x, you'll resolve a swarm of just-visible stars. Larger scopes reveal the richness of the halo and how its brightness slowly fades with distance from the core.

M92 is the "other" globular in Hercules. It glows at magnitude 6.5, measures 11.2' across, and lies 6.3° north of Pi (π) Herculis. Its stars are nearly as bright as those in M13, and they easily resolve through small scopes. A 6-inch instrument at 100x will reveal the slight oval shape, which orients north-south.

OPPOSITE: M16, the Eagle Nebula, is home to the famed "Pillars of Creation" (at center). This image was taken on a 10-inch telescope with over 22 hours of exposure time. MADHUP RATHI

LEFT: The Trifid Nebula (M20; top) and the Lagoon Nebula (M8; bottom) make a spectacular pairing in this wide-field image. The Trifid's reflection nebula is visible in blue. TERRY HANCOCK

BELOW: M23 is an underappreciated gem of an open cluster roughly 2,100 light-years distant. DAN CROWSON

Next up is the **Butterfly Cluster** (M6), the first of a pair of Messier objects in the tail of Scorpius. From a dark site, you'll pick out this bright (magnitude 4.2), large (33') open cluster easily with your naked eyes. It lies 5° north-northeast of Shaula (Lambda [λ] Scorpii).

Start with a low-power eyepiece, and try to pick out the butterfly's wings, one to the north and the other to the south. A 4-inch scope will reveal 50 stars, and through an 11-inch scope, you'll count 200. M6's brightest star is the orange, 6th-magnitude point on the cluster's eastern edge.

Near M6, you'll also find **Ptolemy's Cluster** (M7), which is even brighter (magnitude 3.3) and larger (1.3°). It lies nearly 5° east-northeast of the two bright stars that mark the scorpion's stinger. You'll spot M7 easily from any reasonably dark site.

M7 covers an area as large as four Full Moons, so only a low-power eyepiece will reveal the entire cluster. Alternatively, you can crank up the power and look for embedded features — double stars, patterns the cluster's stars form, or gaps between lines of stars. Plan on spending some serious time doing this.

Keep your observational muscles fit by giving a mini-marathon a try.

Next up is open cluster **M23** in Sagittarius, one of Messier's least-observed objects. That's a shame, because it's gorgeous. You'll find it 4.5° west-northwest of Mu (μ) Sagittarii.

M23 glows at magnitude 5.5 and measures 27' across, a size nearly that of the Full Moon. Through a 4-inch scope at 100x, you'll see 50 stars spreading out into several curving rows. Although the surrounding star field is rich, you'll have no trouble identifying where M23 ends.

One of the finest objects in Sagittarius is the **Trifid Nebula** (M20), whose common name comes from the three dust lanes that converge in front of the brighter nebulosity. You'll find it 3.3° southwest of Mu Sagittarii. The nebula measures 20' by 20' and features a nice triple-star system just west of center. Radiation from these stars makes M20 glow. A reflection nebula, which looks blue in images, lies on the Trifid's northern edge.

Next, look 5.5° west of magnitude-2.8 Kaus Borealis (Lambda Sagittarii) for the magnificent **Lagoon Nebula** (M8). Try to spot it with your naked eyes from a dark site. With a size of 45' by 30', M8 covers three times the area of the Full Moon. A dark lane (the lagoon) cuts the object in half. On the eastern side of the rift, you'll see about 30 stars in

ABOVE: The Swan Nebula (M17) is a star-forming region roughly 5,500 light-years from Earth. It measures about 15 light-years across. CHUCK MANGES

CENTER RIGHT: The famed Ring Nebula (M57) is one of just four planetary nebulae that Messier recorded. However, don't expect to see any color through a small telescope. DON GOLDMAN

LOWER RIGHT: M22 is a globular that spans nearly the width of the Full Moon. DAN CROWSON

BELOW: The Wild Duck Cluster (M11) gets its name from the flying V formation its brightest stars appear to make. JOHN CHUMACK

open cluster NGC 6530 embedded in the gas. Look a bit more to the west, in M8's core, for the Hourglass Nebula, a star-forming region with lots of young stars.

Now head just over Sagittarius' border into Serpens Cauda for the **Eagle Nebula** (M16). It's actually two objects, open cluster NGC 6611 and nebula IC 4703. Together they span 21'. You'll find it 2.5° west-northwest of Gamma (γ) Scuti.

A 6-inch scope reveals about a dozen stars brighter than 10th magnitude along with several dozen fainter ones, giving M16 a three-dimensional appearance. The nebula engulfs the cluster and continues to the south.

Back we go to Sagittarius for the **Omega Nebula** (M17), also known as the Swan Nebula, the Checkmark Nebula, and the Horseshoe Nebula. It lies 2.5° southwest of Gamma Scuti. Through a 6-inch scope, it appears as a bright bar 7' long with a short extension from the west end to the south. Crank the power past 150x, and the extension becomes hook-shaped, with dark material blocking light from its center.

One of the most spectacular objects in Sagittarius is globular cluster **M22**. This easy naked-eye object ranks as the sky's third-brightest globular. It glows at magnitude 5.2, measures 24' across, and lies 2.5° northeast of Kaus Borealis.

Through a 4-inch scope, you'll see several dozen stars. But move up to a 10-inch and hundreds of stars in the cluster will dazzle you.

Next up is **M70**, a southerly globular midway between Ascella (Zeta Sagittarii) and Kaus Australis (Epsilon Sagittarii). M70 glows at magnitude 8.0 and measures 7.8' across. Through an 8-inch scope at 200x, you'll see a bright core with a thin halo around it. A short line of relatively bright stars shoots northward from the cluster's eastern side.

One of my favorite deep-sky objects is the **Wild Duck Cluster** (M11) in Scutum. This open cluster glows at magnitude 5.8 with a diameter of 13'. From a dark site, sharp-eyed observers will spot M11 with their unaided eyes by following a curved line of stars of decreasing brightness. Start with Lambda Aquilae, move to Iota (ι) Aql, and proceed to Eta Scuti, which will lead you to M11.

Use an 8-inch scope and 75x, which will let you see more than a hundred stars. M11 has a core packed so tightly it looks like a globular cluster. Streamers of stars and dark lanes emanate from the central region in all directions.

Our next object, the **Ring Nebula** (M57) in Lyra, is a great target for small scopes. Through a 4-inch, you'll see this planetary nebula as a pale gray ball. With powers above 100x, the outer part of the ball looks thicker than the central region, which gives the distinctive "ring" appearance.

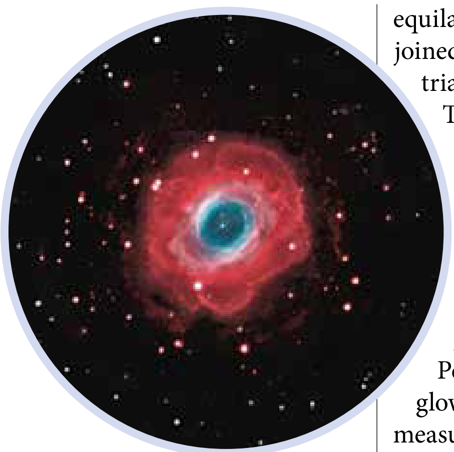
To find M57, locate Beta (β) and Gamma Lyrae. The Ring lies roughly midway between them. It glows at magnitude 8.8 and measures 1.2' across.

Our next object, the **Dumbbell Nebula** (M27) in Vulpecula, is a great one for small scopes. Also known as the Apple Core Nebula, the Diablo Nebula, and the Double-Headed Shot, it glows at magnitude 7.3 and measures 5.8' across.

A 4-inch scope will show

M15 is a core-collapse globular cluster, meaning that over time, stars have become densely packed together at the cluster's center. At roughly 13 billion years old, it's one of the oldest known globulars in the Milky Way. DAN CROWSON

The Dumbbell Nebula was the first planetary nebula that Charles Messier cataloged. This image combines data from Hydrogen-alpha and Oyxgen-III filters for a total exposure of just over 11 hours. CHUCK AYOUB



the two bright lobes and several stars scattered across M27's face. This object responds well to high powers because it has a high surface brightness. Through a large telescope, use an Oxygen-III filter to reveal more detail, and really crank up the magnification.

The fact that **M73** — a grouping of four stars — is a Messier object shows how primitive Charles Messier's telescope was. It sits not quite 3° west-southwest of Nu (ν) Aquarii.

M73 appears as an equilateral triangle of stars joined by a fourth just to the triangle's north-northwest. The combined magnitude is 8.9 and it spans just 2.8'. I put this object on the list because you should see it — once.

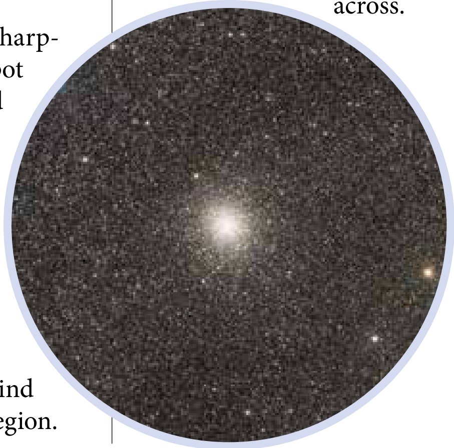
Our next target, globular cluster **M15** in Pegasus, is a showpiece. It glows at magnitude 6.2 and measures 12.3' across. Finding it is pretty easy. Just draw a line from Theta (θ) through Epsilon Pegasi, and continue another 4°. Don't be confused by the 6th-magnitude star only ¼° to the east.

From a dark site, sharp-eyed observers can spot M15 with their naked eyes. But confirm your sighting through your telescope: A 4-inch scope will resolve dozens of stars around the cluster's bright core. Look for chains of stars that wind out from its central region.

Now head south to Aquarius for **M2**, one of the sky's richest and most compact globular clusters. It shines at magnitude 6.6 and has a diameter of 12.9'.

To find it, scan roughly 4.5° due north of Beta Aquarii. If you have sharp eyes, you might spot the cluster with your naked eyes from a dark site. Through your telescope, you'll notice that M2 appears slightly elliptical.

Our final treat, **M30** in Capricornus, lies roughly 3° east-southeast of Zeta Capricorni. It glows at magnitude 6.9 and measures 11' across.



Through a 4-inch scope, you'll see a bright, broad core you won't resolve, surrounded by myriad stars you can resolve. Use a 12-inch scope, however, and crank the power to 300x or more, and the core will explode with detail.

Much more to see

Believe it or not, space allowed me to describe only half of the Messier objects visible in the summer sky. After you've gazed lovingly at the wonders I've listed, you absolutely should check out M9, M14, M19, M62, and M107 in Ophiuchus; M80 in Scorpius; M18, M24, M25, M28, M54, M55, M69, and M75 in Sagittarius; M26 in Scutum; M56 in Lyra; M72 in Aquarius; M71 in Sagitta; and M29 and M39 in Cygnus. Each is worth your time, and the darker your observing site, the better. Good luck!

Michael E. Bakich *is a contributing editor of* Astronomy *who loves searching for details in deep-sky objects.*

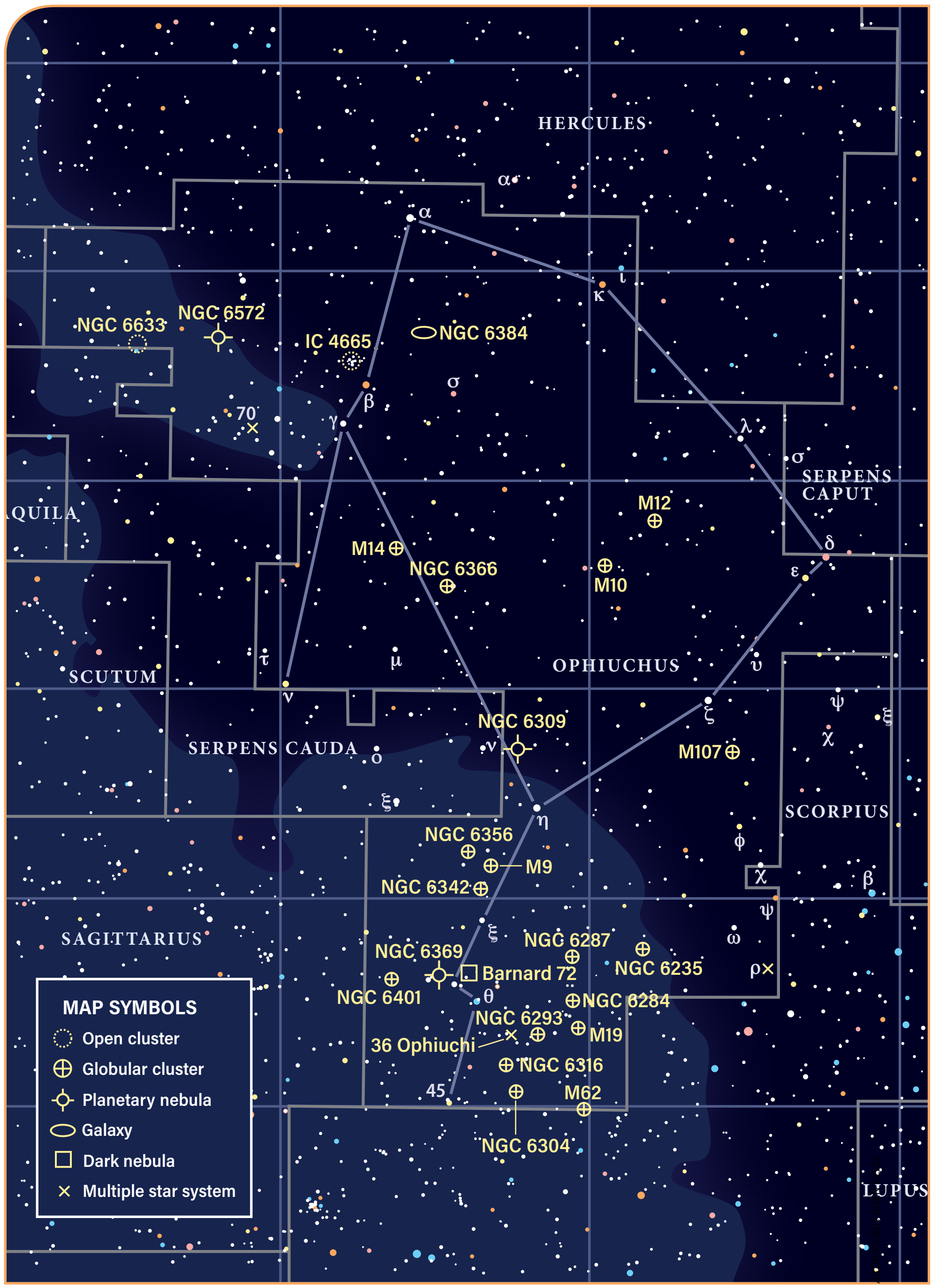
Discover deep-sky g

With seven Messier objects and many other bright targets, the Serpent-bearer has a lot going for it. BY MICHAEL E. BAKICH

The constellation Ophiuchus (pronounced off-ee-OO-cuss) the Serpent-bearer isn't all that easy to pick out, primarily because of its large size and the relative dimness of its brightest star, Rasalhague (Alpha [α] Ophiuchi). This giant white star emits about 25 times the light of the Sun, but sits some 50 light-years away, so it glows at magnitude 2.1 — just slightly fainter than Polaris (Alpha Ursae Minoris). That makes it the 56th-brightest nighttime star. Only four other stars in Ophiuchus make the list of the top 200 brightest stars in the sky: magnitude 2.4 Sabik (Eta [η] Ophiuchi) is the 83rd brightest; magnitude 2.6 Zeta (ζ) Ophiuchi is 95th; magnitude 2.7 Yed Prior (Delta [δ] Ophiuchi) is 115th; and magnitude 2.8 Cebalrai (Beta [β] Ophiuchi) is 122nd.

The Serpent-bearer ranks 11th in size out of 88 constellations, covering 948.34 square degrees (2.3 percent) of the sky. Ophiuchus is visible in the evening from late spring through early autumn in the Northern Hemisphere, and its center lies at right ascension 17h20m and declination –8°. The best date each year to see Ophiuchus is June 11, when it stands opposite the Sun in the sky, reaching its highest point at local midnight. With respect to visibility, anyone living north of latitude –76° and south of latitude 60° can view the entire figure at some point during the year. And because it lies near the celestial equator, portions of Ophiuchus are visible worldwide.

The Serpent-bearer contains seven Messier objects — all globular clusters — as well as many other non-Messier globulars. Apart from those, it features three nice planetary nebulae, several worthy open clusters, and even a spiral galaxy. The last is a surprise because this star figure lies along the Milky Way, which normally blocks the light from objects such as distant galaxies.



ASTRONOMY: KELLIE JAEGER

Get comfortable, take your time, and enjoy your trek through this remarkable region of sky. Good luck!

Michael E. Bakich *is a contributing editor of* Astronomy *who enjoys slowly moving his telescope through a single constellation.*

ems in OPHIUCHUS

1 Astronomers named the Rho Ophiuchi region for the magnitude 4.6 double star Rho (ρ) Ophiuchi. Look for a variety of emission (red) and reflection (blue) nebulae, as well as Barnard 44, a dark nebula that stretches 6.5°. FERNANDO MENEZES

2 Globular cluster M12 lies some 8° east-northeast of Yed Posterior (Epsilon [ε] Ophiuchi). It glows at magnitude 6.1 and measures 14.5' across, roughly half the width of the Full Moon. DAN CROWSON

3 Because globular cluster M10 lies some 14,000 light-years away, intervening dust dims its stars by nearly a magnitude. Still, it glows at magnitude 6.6 and is an easy catch through binoculars. ALAN DYER

4 The Box Nebula (NGC 6309) glows softly at magnitude 11.5. However, because it spans only 18", you'll have to spot it through a 6-inch or larger telescope. Crank the power past 250x to see the Box's shape; an Oxygen-III filter will help. RAY AND GEOFF WEAVILL/ADAM BLOCK/NOAO/AURA/NSF

5 The Snake Nebula (Barnard 72) is a cloud of dust and cold gas. Your best views of it will come through a telescope and eyepiece combo that yields a field of view around ½°. To find it, look 1½° north-northeast of Theta (θ) Ophiuchi. ALAN DYER

6 NGC 6384, the single spiral galaxy in Ophiuchus worth observing, is magnitude 10.4. It lies 3.7° northwest of Cebalrai (Beta [β] Ophiuchi) and measures 6.2' by 4.1'. You'll see its roughly rectangular shape through an 8-inch scope at 150x. JIM AND JANET CASTANO/ADAM BLOCK/NOAO/AURA/NSF

7 The Captain Hook Cluster (NGC 6633), located toward the upper right of this image, is an open cluster that shines at magnitude 4.6 and measures 27' across. You'll find it 8° west-northwest of Alya (Theta [θ] Serpentis). Keep the magnification low through large scopes so you don't look "through" this cluster. Open cluster IC 4756 in Serpens is also visible at left here. ALAN DYER

8 The Emerald Nebula (NGC 6572) lies 2.2° south-southeast of 71 Ophiuchi. Although this planetary is small, it has a high surface brightness and is quite colorful. This shot was taken using a 5.1-inch refractor, but an 8-inch or larger scope will reveal the Emerald's oval shape. ALAN DYER

9 The Black Swallowtail Butterfly Cluster (IC 4665) — seen here above the cyan-tinted star Cebalrai — is a relatively bright open cluster at magnitude 4.2. It won't look bright, however, because it measures 70' across. That means it covers 5½ times the area of the Full Moon. Observe it through a low-power eyepiece. ALAN DYER

Here come the PERSEIDS!

One of astronomy's most popular sky events will 'rain' again in 2021. BY MICHAEL E. BAKICH

SUMMER IS A WONDERFUL season. It's warm, people travel more, and, in 2021, the Perseid meteor shower will put on a great display. We encourage you to head to a dark observing site and enjoy the show, which peaks in the middle of the week.

Perseid meteors create long, bright streaks at night that are easily visible to the naked eye. In fact, I'd recommend leaving your telescope at home, as using one will limit your view so much that chances are slim you'll see a meteor through it. Binoculars, on the other hand, take in more of the sky. While you shouldn't watch the shower through them, they will make any smoke trails left by bright meteors easier to see.

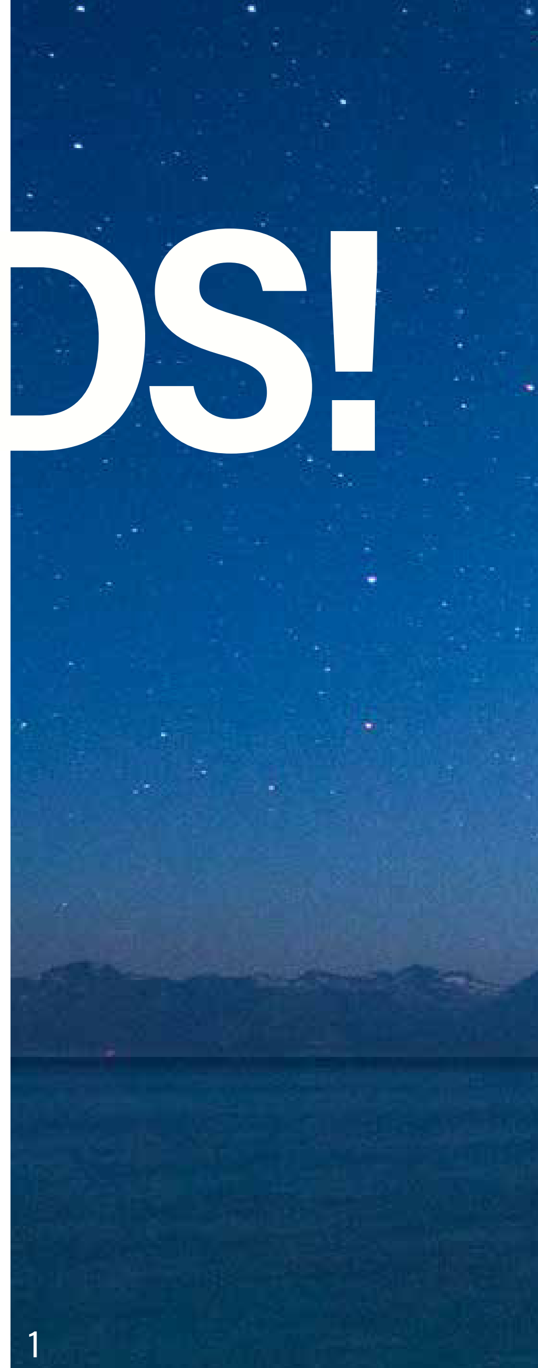
In 2021, the Perseids peak midday on Aug. 12 in the U.S. The best time to view them will be either Wednesday night the 11th through Thursday morning the 12th, or Thursday night the 12th through Friday morning the 13th. The Moon, which is the determining factor in how great a show each year's Perseids will put on, will be a thin crescent only three to four days past New, so it will set in the early evening, before the main event begins.

What's going on?

A meteor is a small (think grain of sand) particle of rock or metal that enters Earth's atmosphere, begins to glow because of friction, and creates a blazing column of gas as it burns up. No meteor from a shower is big enough to survive the burn and land on Earth as a meteorite.

Most meteor showers come from comets. When comets approach the Sun, our star's heat turns the comet's ice to gas. This frees trapped dust particles that continue to orbit the Sun along the comet's path. (December's Geminid meteor shower is an exception to this rule, as its particles originated with an asteroid, 3200 Phaeton.) These particles are called meteoroids. When Earth encounters this trail of particles — which occurs around the same date each year — they enter our atmosphere and create a meteor shower.

Perseid meteors are particles from Comet 109/P Swift-Tuttle.



1

2

1. Despite the bright moonlit sky, a meteor appears to fall to Earth above Bonsai Rock in Lake Tahoe, Nevada, in 2017. Lake Tahoe is North America's largest alpine lake and the second-deepest lake in the U.S. TONY ROWELL, SUGURU ARAKI

American astronomers Lewis Swift of Marathon, New York, and Horace Tuttle, at Harvard Observatory in Cambridge, Massachusetts, discovered the comet in July 1862, when its brightness was magnitude 7.5. Within just two months, however, it reached magnitude 2. Swift-Tuttle orbits the Sun every 133 years and 102.3 days. It last came closest to the Sun on Dec. 11, 1992.

The Perseids' name comes from the rule that a meteor shower is named for the constellation that contains its radiant, which is the point on the sky from which all the meteors seem to originate, or radiate. So, if you plotted all the trails from any meteor shower on a star map, then traced those trails backward, they would all intersect at one point — the radiant. The position of the radiant is important. The higher it is, the more meteors you'll see.

The lone major meteor shower that seems to contradict this rule is the Quadrantids, which peak in early January. But its name actually follows the rule — in this case, however, Quadrans Muralis, the constellation it's named after, no longer exists. When the International Astronomical Union formalized the constellation boundaries in 1928, Quadrans Muralis disappeared and became part of the constellation Boötes.

2021 forecast

Although this year's Perseids peak Aug. 12, the shower actually begins when Earth reaches the edge of the meteoroid stream July 17 and continues until our planet exits it Aug. 24. Of course,

2. The photographer posed in front of his camera for 10 out of 24 total seconds of exposure time during the 2016 Perseids. His shot, taken at Red Rock Canyon State Park in California, features two meteors: In addition to the brightest streak, a second meteor appears near the top of the image, to the upper left of the Pleiades star cluster. NASIR JEEVANJEE

3-4. A Perseid meteor leaves a brief, long train behind in the sky on Aug. 12, 2013. JAMIE COOPER

5. Doubling Point Lighthouse stands vigil on Maine's Kennebec River beneath a Perseid fireball in 2020. The photographer combined eight stacked shots of the Milky way (15 seconds each) with a 15-second exposure of the meteor and a four-second foreground image to create this tranquil scene. ABHIJIT PATIL

FAST FACTS ABOUT METEORS

- You must be less than 120 miles (200 kilometers) from a meteor to see it.
- Meteors become visible at an average height of 55 miles (90 km). Shower meteors burn up before they reach an altitude of 50 miles (80 km).
- No shower meteor has survived its flight through the atmosphere and been recovered as a meteorite. They're just too small.
- The typical bright meteor is produced by a particle no larger than a pea with a mass less than 1 gram. The meteors you'll see during a shower are even smaller. Their size is roughly that of a grain of sand.
- Astronomers estimate that the average total mass of meteoritic material entering Earth's atmosphere is between 100 and 1,000 tons (91,000 and 910,000 kilograms) per day.
- The typical rate for meteors bright enough to see with unaided eyes on a "non-shower" night is approximately six per hour. Astronomers call these random streaks sporadic meteors.
- A meteoroid from the Perseid shower enters the atmosphere at an average speed of 133,000 mph (214,000 km/h).

the farther you observe from the peak, the fewer Perseids you'll see.

The main question each year for any meteor shower is, "How many meteors will we see?" Meteor observers start with a number called the Zenithal Hourly Rate (ZHR). The ZHR for any shower is the number of meteors per hour that an observer could see under a true-dark sky (no scattered light), assuming that the radiant is at the zenith (the point directly overhead). The Perseids' ZHR is 110.

If you start observing on the 11th or 12th at the end of astronomical twilight (the moment no sunlight remains in the sky) when the radiant is low on the horizon, you can expect to see perhaps 20 Perseids per hour, or perhaps a few less because the crescent Moon will still be up. Its light will mask some of the fainter meteors, although the bright ones will still be easy to see. The hourly number will increase as the radiant climbs higher.

Observers generally record higher hourly rates after local midnight because Earth has rotated so their location is heading into the stream. Before midnight, meteors must catch up with Earth. So, taking into account the increase in the rate after midnight, you might expect to see 60 meteors per hour

6. The town of Mountain Mesa, California, appears almost under siege as meteors rain down during the 2013 Perseid meteor shower. This stunning 30-second image was captured just after midnight on Aug. 13, 2013, from Hanning Flat, facing the southern end of the Milky Way. CASEY JAMES

7. A bright Perseid meteor streaks through the sky above a clear lake in Fulton County, Illinois. This 25-second-long shot was taken during the 2018 Perseid meteor shower. JOSHUA RHOADES

8. This composite image fuses a fireball in the skies above Maine's Popham Beach State Park with the shoreline of Boulder Beach in Acadia National Park. The images were captured a week apart during the 2019 Perseids; the photographer later combined and edited the final image using Lightroom and Photoshop. ABHIJIT PATIL

from a dark observing site. Note, though, that this doesn't mean "one per minute." Meteor arrivals are notoriously random. You might see six over the course of one minute and then none for the next 15.

The plan

Meteor watching can be an enjoyable social event. The atmosphere is casual, so you can carry on conversations, eat, and record your sightings. You can choose to watch for five minutes or five hours. Obviously, your viewing odds go up the longer you watch.

As I mentioned earlier, no telescope is required, but a few items will make the night more comfortable for you. The most important is a reclining chair. The best plan is to face a region of sky about 30° away from the radiant. For reference, an angle of 30° is one-third the distance from the horizon to the zenith.

Other things you might want to bring are insect repellent, light snacks, and a warm or cold drink, depending on where you're observing. If your weather is likely to be a bit cold, packing a blanket is a good idea. If you observe at a location with high humidity, a simple plastic tarp will keep you dry all night.

This is the year

If you commit to watching the Perseid meteor shower for more than just a few minutes, it will not disappoint you. The high number of meteors per hour and relatively warm northern nights make this an easy event to view. And this year, the Moon won't be a problem. In fact, the next time the Moon will be this favorable for Perseid watching is 2025. So, pick a dark observing site, grab some friends, and go see stars fall from the sky.

Michael E. Bakich *is a contributing editor of* Astronomy *and a veteran observer of Perseid meteor showers.*

Meet Stellarvue's SVX 152T

This telescope will take your astrophotography to the next level. BY JONATHAN TALBOT

It took me two nights to capture the right wing of the Seagull Nebula, seen above, using my Stellarvue SVX 152T (right) and ZWO ASI 6200 camera at a private astronomy ranch near Lake Okeechobee in southern Florida.
RIGHT: STELLARVUE

Since Stellarvue's founding more than 20 years ago, optical excellence has been the driving force behind their production of top-tier refracting telescopes. Over the years, Stellarvue has refined their designs and manufacturing techniques, added sophisticated equipment, and trained a corps of master opticians. They currently offer refractors ranging in size from 3 inches to 6 inches. Their largest is the SVX 152T, a 6-inch f/8 apochromatic refractor.

As an astrophotographer, I wanted a telescope that excelled at several things: providing extremely well-corrected optics, easily handling a large 35mm-format camera, and offering a focal length long enough to enable both wide fields of view and relatively high resolution. Because it meets these criteria, I was eager to test Stellarvue's highly rated SVX 152T.

Unpacking

The SVX 152T ships in a box about the size of a refrigerator and is packed with foam and double-layered cardboard. A robust, hard-sided carrying case with wheels further protects the scope. The case is extremely well made, with riveted aluminum framing around all the edges, and lined with a foam cutout to fit the scope. Twist-locking latches keep the case closed. There are handles on each end to allow two people to easily carry the case, if needed. Inside the case was a user manual and an envelope containing the objective report of the scope, measuring its specific optical quality using the Strehl ratio.

Let's pause and go over what this number means. The Strehl ratio is one measure of optical excellence used by amateur and professional astronomers alike. A lens or mirror with a Strehl ratio of 1 is theoretically perfect. So, ideally, you want your optics to rate as close to 1 as possible.

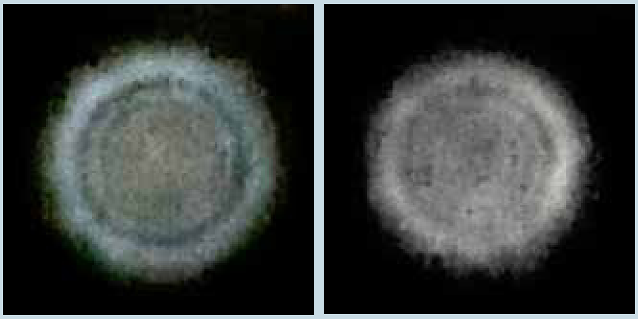
These days, machined optics typically reach 0.95 Strehl. If a manufacturer wants to get a mirror or lens with a better value, they'll need to further refine it by hand, which is a time-consuming art that takes years to perfect. But Stellarvue has reached that higher standard. The SVX line of refractors from 102mm and up all boast hand-figured objectives with a minimum Strehl ratio of 0.99, while the 80mm variants achieve a 0.98 Strehl ratio.

According to the report, my scope measured 0.997 Strehl.

Setup

The SVX 152T weighs 27 pounds (12 kilograms), including the rings and a dovetail plate. However, there may be some variation depending upon which focuser you order with the scope. As an imager, I selected the 3.5-inch MoonLite NightCrawler, a fantastically accurate focuser with a built-in rotator. Your other option is the 3.5-inch Feather Touch from Starlight Instruments. The Feather Touch can be fitted with excellent

ALL PHOTOGRAPHS BY JONATHAN TALBOT, UNLESS OTHERWISE NOTED



Shown here are the cellphone images I captured while performing the star test with the artificial light. You can see that the inside (left) and outside (right) of focus images look almost exactly the same and are both nice and crisp. These images were taken using a Celestron NexYZ adapter to hold my phone.

autofocus systems from Optec, Starlight Instruments, or other manufacturers. This is a great option if you plan on mixing visual observing with imaging.

The SVX 152T is a big scope, nearly 5 feet (1.5 meters) long with its sliding dew shield extended and a camera — as well as either spacers or a diagonal — added. This means it should be paired with a stiff mount. My ZWO ASI6200 camera and EAGLE3 Pro computer brought the total weight close to 40 pounds (18 kg).

I used a Software Bisque Paramount MYT mount with a recommended max imaging weight of 50 pounds (22.6 kg), so I was pressing the limit. In my observatory, where I'm protected from wind, I haven't had any issues at all. However, in the field at a star party, I would likely need to put up a wind break to protect my setup.

Getting started

With any new scope, I always begin with star testing to ensure the optics are in good shape. I use Harold Richard Suiter's wonderful book *Star Testing Astronomical Telescopes* (Willmann-Bell, 2009), which explains how to test each type of telescope, as my reference.

PRODUCT INFORMATION

Stellarvue's SVX 152T
Aperture: 6 inches (152 mm)
Focal length: 1200 mm
Focal ratio: f/8
Weight: 27 pounds (12.2 kg)
Price: $8,995 with Feather Touch Focuser, $11,699 with Moonlight Focuser upgrade
Contact: Stellarvue
11802 Kemper Road
Auburn, CA 95603 USA
530.823.7796

Testing the SVX 152T on a real star proved the optics are excellent, but thanks to Earth's turbulent atmosphere, I had only fleeting moments to see the diffraction rings come in and out of focus. Following Suiter's guide, I used an artificial star to reduce those effects. Suiter says that for a 6-inch f/8 optical system, using a point source with a 0.1-millimeter aperture placed at a distance greater than 80 feet (24 m) should be sufficient, although it may cause a bit of undercorrection.

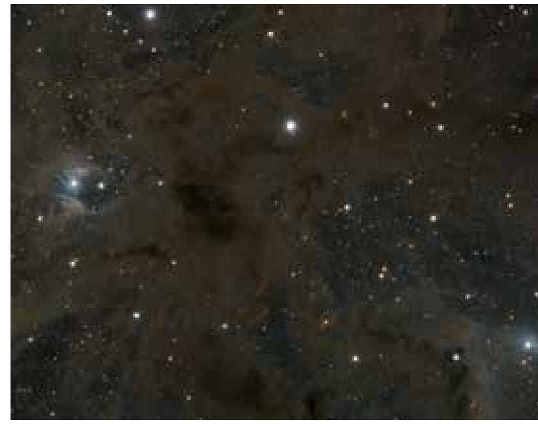
To perform my test, I used a small artificial star device that has several different size apertures, including a tenth of a millimeter. I equipped the scope with a 5mm Takahashi eyepiece at 241x magnification. After placing the scope on a table, I moved the light source 100 feet (30 m) away and ran the test. I saw only a slight difference between the rings, with the outside focus just a bit more defined. This was due to the slight undercorrection expected from the short distance to my artificial star.

I did my best to document the star test, but getting images proved harder than I expected, as a bit of turbulence still existed across the grassy surface of my backyard. The resulting cellphone images (shown above) are much less defined than what I visually saw through the eyepiece.

In the field

I've used this scope for over a year now and the tracking and guiding are excellent, as long as I can keep the wind off it. But wind is a problem for any larger scope and a wind shield is more than enough to solve that problem. The scope also cools down quickly, thanks to its aluminum tube.

The MoonLite NightCrawler focuser is



On the border of Taurus, Perseus, and Aries lies an extremely dusty area known as the Barnard 204 region. I captured this image using an ASI 6200 camera with Luminance, Red, Green, and Blue filters and 7.7 hours exposure time.

optimized for imaging, but it is also easy to use visually. While I don't do a lot of visual observing from home, the few times I have, this scope provided views of an inky black sky background and crisp point sources that would snap into focus. Lunar observing was just as rewarding. My views of the First Quarter Moon were absolutely mesmerizing, with ultrasharp detail and wonderful contrast.

Using a ZWO ASI 6200 35mm-format camera along with a Stellarvue field flattener, my test images showed that the scope is an outstanding performer for imaging. From the hot weather in the summer to below-freezing temperatures in the winter, I have yet to see any signs of aberrations or issues with the lens cell. The images I've been able to take over the past year, either from my suburban home skies or at dark sites, have been the best I've ever captured, thanks in part to this refractor's ultrahigh Strehl ratio.

Discriminating visual observers looking for a large refractor with near-perfect hand-figured optics capable of showing exquisite detail will find it in Stellarvue's SVX 152T. And astrophotographers aspiring for an imaging scope able to deliver high-resolution, extremely sharp shots with well-corrected, wide fields of view should also consider this scope. I couldn't be happier with the performance. The superb workmanship that has gone into producing this telescope has taken my astrophotography work to the next level.

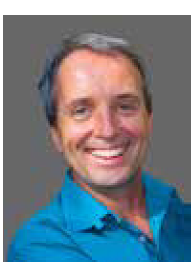
Jonathan Talbot *is a retired Air Force Hurricane Hunter and has been photographing the night sky for the past 20 years.*

Jupiter through binoculars

Trying to replicate Galileo's observations is harder than it sounds.

1

2



BY STEPHEN JAMES O'MEARA

Stephen is a globe-trotting observer who is always looking for the next great celestial event.

Jupiter is entering our night skies again after sunset — just in time for a project you can undertake in the coming months. All that's required are a pair of handheld binoculars and some patience.

Before we start, I have to admit that after more than a half century of observing Jupiter, I always took for granted one simple statement: that Jupiter's four Galilean satellites can be seen through binoculars. While that statement is true in a general sense, I never gave thought to the nuances involved in detecting these moons as their positions shift relative to one another and to their parent planet.

Jupiter's four Galilean satellites can be seen through binoculars.

The challenge

The awakening, for me, came the morning of June 10, 2020, when I trained a pair of 8x42 binoculars on Jupiter at 4:21 UT from Maun, Botswana, shortly after the start of astronomical twilight. A waning gibbous Moon was nearby, which also helped illuminate the background sky and cut down on contrast. With a glance, I saw three moons. And had I put down the binoculars, I would have left it at that — assuming that the fourth moon was either behind or in front of the planet, or very close to its edges.

But as I fiddled with the focus, I suddenly saw the moon closest to Jupiter take on an egg-shaped appearance. When I braced the binoculars against the hood of my car, I resolved the "egg" into two close moons.

On July 4, 2020 at 18:47 UT, I used the same binoculars to observe Jupiter. This time, a prolonged study revealed two moons, Ganymede and Callisto, on opposite sides of the planet. I then used a telephoto lens to image Jupiter. To my surprise, the image showed another moon (Europa) only about 16" east of Jupiter's disk; Io was occulted by the planet.

Try as I might, I could not see Europa through the 8x42s, nor in 10x40s. The moon was, however, *just* visible through 10x50s, though both stabilized binoculars and patience were required to pull it out from the planet's glare.

Two weeks later, on July 18 (18:00 UT), three moons were visible (Callisto, Europa, and Ganymede) through 8x42 binoculars. Europa, however, was only seen with difficulty, even though it was roughly one Jupiter diameter (47.5") to the west of the planet. I found this the most surprising sighting of all, as I had expected that moon to be clearly visible at this apparent separation.

Thoughts on Galileo

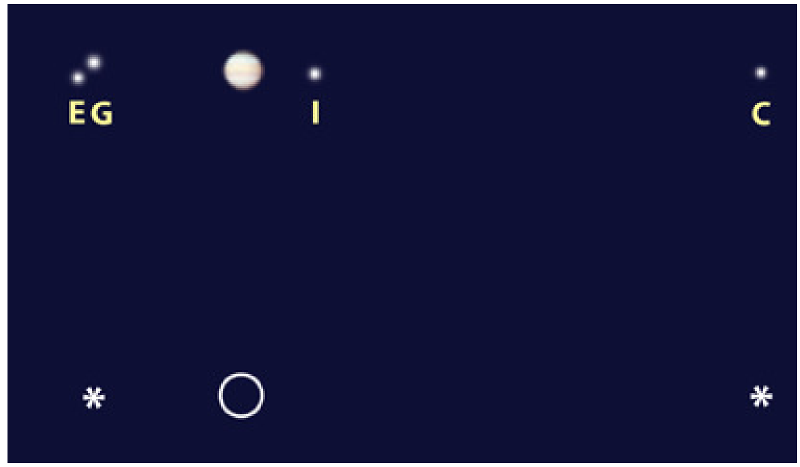
On Jan. 7, 1610, in the first hour after twilight, Italian astronomer Galileo Galilei observed, and drew the positions of, what he believed were three fixed stars near Jupiter. These turned out to be moons — a fact revealed to him over the course of months. Notice, however, that I do not say that "he discovered three of the four Galilean moons."

Using Fifth Star Labs' Sky Guide app, I checked the positions of the moons for that date and time against Galileo's original drawing. I was surprised to find that one of the moons he saw was actually the combined light of Europa and Io, which were passing close to one another during the first hour of nightfall. Had he observed a couple of hours later, the moons would have been further apart and identifiable as four distinct objects.

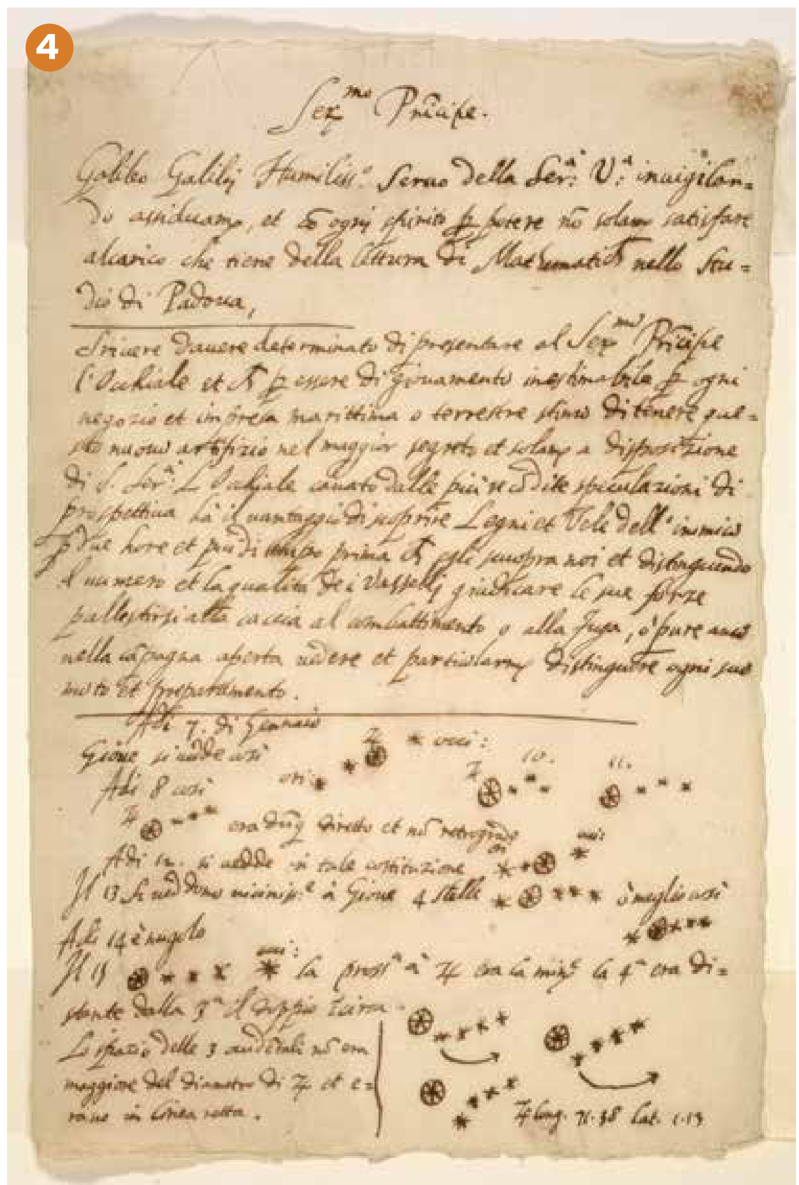
Similar situations occurred over the course of Galileo's later observations, where he could not resolve

1. A 200mm (effective focal length [EFL] 320mm) telephoto lens image of Jupiter on the morning of June 10, 2020, showing Io and Europa immediately to the left (east) of Jupiter. These moons initially appeared as a single object to the author, who was using 8x42 binoculars. North is up. STEPHEN JAMES O'MEARA

2. A 200mm (EFL 320mm) telephoto lens image of Jupiter on the night of July 4, 2020, showing Ganymede at far left (east), Callisto at right (west), and Europa just east of the planet — too close to be resolved through 8x42 binoculars; Io was behind the planet. North is up. STEPHEN JAMES O'MEARA



3. A photo-illustration of the way Jupiter's moons appeared on the night of Jan. 17, 1610 (top), compared to a reproduction of Galileo's sketch of the two "stars" he observed (bottom) that night. STEPHEN JAMES O'MEARA



Ser.mo Principe.

Galileo Galilei Humiliss.o Servo della Ser.tà V.a invigilan-do assiduam.te, et con ogni spirito per potere non solam.te satisfare al carico che tiene della lettura di Matematiche nello Stu-dio di Padova,

Hauere determinato di presentare al Ser.mo Principe l'Occhiale et quello poter essere di giovamento inestimabile per ogni negozio et impresa marittima o terrestre stima di tenere que-sto nuovo artifizio nel maggior segreto et solam.te a disposizione di V. Ser.tà. L'Occhiale cavato dalle più recondite speculazioni di prospettiva ha il vantaggio di scoprire Legni et Vele dell'inimico due hore et più di tempo prima che egli scuopra noi et distinguendo il numero et la qualità dei vasselli giudicare le sue forze pallestirsi alla caccia al combattimento o alla fuga, o pure ancora nella campagna aperta vedere et particolarm.te distinguere ogni suo moto et preparamento.

Adi 7 di Gennaio Giove si vedeva col cannone con 3 stelle fisse così

Adi 8 così era dunque diretto et non retrogrado

Adi 12 si vedde in tale costituzione

Il 13 si veddono vicinissime a Giove 4 stelle o meglio così

Adi 14 è nugolo

Il 15 la prossima a Giove era la minore la 4a era distante dalla 3a il doppio incirca.

Lo spazio delle 3 occidentali non era maggiore del diametro di Giove et erano in linea retta.

Giove long. 71.38 lat. 1.13

4. Galileo sometimes sketched his initial thoughts and observations on scratch paper before entering them into his logbook, as in this example. This top portion of this page contains a rough draft of a letter Galileo was writing to the doge of Venice. On the rest of the page, he scribbled down observations of Jupiter Jan. 7–15, 1610, noting how the "stars" appeared to move around it. UNIVERSITY OF MICHIGAN LIBRARY (SPECIAL COLLECTIONS LIBRARY)

close pairings of moons. But I was impressed by his accurate deduction of the events on the night of Jan. 17, 1610, when, at about 30 minutes after sunset, he saw, initially, only two "stars":

> The easterly star [the combined light of Ganymede and Europa] was distant from … Jupiter by 3'. The westerly [Callisto] by 11'. The easterly seemed twice greater [in brightness] than the other [westerly star]. No more than these two stars were visible. But … on the 5th hour, a third star began to appear which, as I conjecture, was joined with the easterly one and such was their appearance.

A fourth moon (Io) was also visible that night, but Galileo did not resolve it — even though the moon was a little more than a Jupiter-width to the west.

What I gained from these experiences attempting to reproduce Galileo's observations was a crisp understanding of the challenges he had to overcome in order to puzzle out the mysterious motions of these new worlds. I also gained an increased admiration for the man whose observations with an inferior instrument missed nothing that a modern observer today would have seen through binoculars. As always, send your observations and thoughts to sjomeara31@gmail.com.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara**

A gaggle of globulars

This month, let's wind our way through Ophiuchus.

Two dozen globular clusters lie within Ophiuchus' borders. M9 (left) and M14 (right) are both visible to discerning binocular observers. LEFT: BERNHARD HUBL. RIGHT: AL KELLY

Between the stars Altair (Alpha [α] Aquilae) and Antares (Alpha Scorpii) and just west of the Milky Way's stream lies a large asymmetrical hexagon of half a dozen faint stars that outline the constellation **Ophiuchus**.

The ancient Greeks saw Ophiuchus as embodying Asclepius, the god of medicine. According to legend, Asclepius once killed a snake with his staff. But a second snake brought the first back to life using mystical herbs. Witnessing this, Asclepius began using those same herbs on people to bring them back from the dead.

To commemorate his healing powers, Asclepius was placed in the sky as Ophiuchus the Serpent-bearer. He is depicted with the serpent's head, Serpens Caput, and tail, Serpens Cauda, in either hand.

For backyard astronomers, Ophiuchus is best known as being home to 24 globular star clusters — more than any other constellation except Sagittarius. This month, let's visit four of Ophiuchus' globulars.

We'll begin with the brightest two, **M10** and **M12**. Both lie just south of the hexagon's center. To find M10, first locate the stars that form the southern boundary of Ophiuchus, just north of the head of Scorpius. The line kinks a little to the south in the middle, to the star Zeta (ζ) Ophiuchi. Glance 6° — about one field of view — northeast of Zeta for 5th-magnitude 23 Ophiuchi. Look for the soft, circular glow of M10 2.5° northeast of 23 and 1° west of neighboring 5th-magnitude 30 Ophiuchi.

Once you locate M10, shift your attention toward the northwest edge of the field without changing your binoculars' aim. Can you see another circular patch? That's M12. Both are evident through most binoculars, with M10 shining at magnitude 6.4 and M12 reaching magnitude 7.7.

Messier discovered M10 and M12 just a day apart in late May 1764. In both cases, he referred to his new finds as "nebula[e] without stars." That pretty much mirrors our view through binoculars. Each looks like a tiny cotton ball floating among the stars. But there is so much more there. Globular clusters are huge spherical agglomerations of 100,000 or more of the oldest stars known. The stars in M10 are estimated to be 11.4 billion years old, while those in M12 are a billion years older still.

It is interesting to compare the two, since both are in the same field of view. At first glance, they look identical, but the discerning eye can see subtle differences. M10 appears slightly brighter and slightly larger than its neighbor. Notice also that M10 shows a more prominent central core than M12. That's due in part to their differences in stellar density. M10's stellar concentration is rated Class VII on the Shapley-Sawyer 12-point globular cluster concentration scale. On this scale, the lower the Roman numeral, the higher the cluster's central concentration. M12 is rated Class IX. Through giant binoculars, such as my 25x100s, each shows a graininess, as if on the verge of resolution.

Messier also discovered globular cluster **M9** in May 1764. M9 is found 3.5° southeast of Sabik (Eta [η] Ophiuchi), along the constellation's southern boundary. M9 appears smaller and a full magnitude fainter than M10 and M12. That's thanks to all the intervening clouds of interstellar dust. M9 is Class VIII, with a prominent central core that helps it to stand out.

Messier referred to M10 and M12 as "nebula[e] without stars."

Finally, aim about two-thirds of the way between Sabik and Cebalrai (Beta [β] Ophiuchi) along the hexagon's eastern side. There, you will find **M14**, just as Messier did when he discovered it June 1, 1764. Like M9, when we look toward M14, we are seeing it through obscuring clouds of interstellar dust. That diminishes its brightness by two full magnitudes to a challenging 8th magnitude. Had we a clear view, M14 would outshine M9, M10, and M12, even though it is the most distant of the four. Like M9, M14 is rated Class VIII on the Shapley–Sawyer scale. Through most binoculars, it looks like a small blur of light hidden in a field rich in stars.

I welcome your questions, comments, and suggestions for future topics. Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT **www.Astronomy.com/Harrington**

NASA/SDO/USPS

Solar stamps

United States Postal Service

Washington, D.C.

The United States Postal Service's "Sun Science" Forever stamps highlight 10 images from NASA's Solar Dynamics Observatory. They are a celebration of the ongoing exploration and study of our nearest star. This set comes with a total of 20 stamps, featuring images in multiple wavelengths showcasing common solar events such as solar flares, sunspots, and coronal loops.

$11.00
800.782.6724
www.store.usps.com

Zoom eyepiece

Orion Telescopes & Binoculars

Watsonville, California

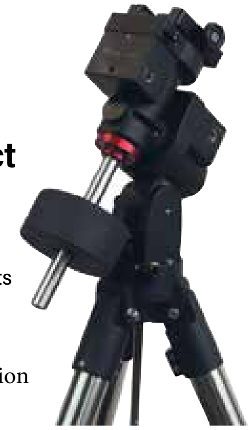
Orion's 7.2-21.6mm Zoom Telescope Eyepiece allows users to change magnification without switching eyepieces. It has a barrel size of 1.25" and provides 20 millimeters of eye relief. Each of the seven lens elements is fully multicoated. The eyepiece measures 3.6 by 2 inches (91 by 51 millimeters) and weighs 8 ounces (227 grams).

$129.99
800.447.1001
www.telescope.com

Compact mount

iOptron

Woburn, Massachusetts



The iOptron GEM28 is a next-generation German equatorial mount. Weighing in at just 10 pounds (4.5 kilograms), it can support up to a 28-pound (12.7 kg) payload. The mount has built-in Wi-Fi and comes with either a 1.5" standard or 1.75" LiteRoc tripod. While perfect for those that prefer a traditional mount, the GEM28 is also ideal for higher latitudes (over 60°).

$1,098.00
866.399.4587
www.ioptron.com

Attention, manufacturers: To submit a product for this page, email **products@astronomy.com**.

INDEX *of* ADVERTISERS

The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.

Astrophotographer Jeff Dai captured this image of the Perseids over the Rainbow Mountains of Zhangye Danxia National Geological Park in the Gansu province of China.
JEFF DAI

Replenishing meteor showers

Q WHY DO WE STILL HAVE METEOR SHOWERS? IF EARTH IS 4.5 BILLION YEARS OLD, THEN IT'S TRAVELED THROUGH THESE METEOR FIELDS 4.5 BILLION TIMES. SO WHY HAVEN'T ALL THE METEORS BEEN PULLED OUT OF OUR ORBIT BY NOW?

Dwain Smith
Sugar Land, Texas

A Since the moment it coalesced, Earth has had meteor showers. In the young solar system, the region near the Sun was crammed full of large objects that formed when the gravitational attraction among tiny particles brought them together. Meteorites (the largest of which could be called asteroids) continually struck Earth's surface and even contributed to our planet's eventual mass.

After more than 4 billion years, the space between the planets has been swept clean of that initial material. But visitors from the depths of the solar system keep replenishing the supply, if only by adding dust-size particles. These visitors are comets, frozen balls of dirty ice when far from the Sun. But when its orbit carries a comet close to our star, solar radiation boils the ice from its surface and creates a glowing tail of gas. It also releases particles of dust trapped in the ice, generating a second tail of dust that reflects sunlight.

This process, however, does more than produce a pleasant sight through a telescope or, occasionally, even to the naked eye. The released particles of dust persist, strewn along the comet's path. If that path happens to cross Earth's orbit, our planet will run into the particles at the same time each year. When it does, the particles enter our atmosphere and burn up, producing a meteor shower.

This can happen even if the comet is a one-time visitor that will never return. But the persistent meteor showers like the Perseids in August and the Geminids in December are created by periodic comets that do return. The most famous example of a periodic comet, and the first one recognized as such, is Halley's Comet, which last came close to the Sun in February 1986. It orbits once every 75⅓ years, meaning it will again be closest to the Sun in 2061.

Each time a periodic comet returns to our neck of the woods, it replenishes the dust particles along its path, allowing us to enjoy meteor showers to this day.

Michael E. Bakich
Contributing Editor

Q DO BARRED GALAXIES HAVE TWO OR MORE SUPERMASSIVE BLACK HOLES IN THE CENTRAL REGION? CAN A SINGLE BLACK HOLE IN THE CENTER CREATE A BAR?

Nicolas Andreyev
Estes Park, Colorado

A Barred spiral galaxies are fairly common throughout the universe — at least one-third to one-half of spiral galaxies show some kind of central bar structure, including our own Milky Way. Because bars form in the centers of galaxies, which is also where

NGC 1300 is a barred spiral galaxy which spans more than 100,000 light-years. Its central supermassive black hole is estimated to be around 66 billion solar masses, but even that is lightweight compared to the mass of the galaxy's central bulge.
HUBBLE HERITAGE TEAM, ESA, NASA

SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

supermassive black holes reside, it's easy to think the two are connected. However, the gravitational influence of a galaxy's supermassive black hole is so limited that it has nothing to do with how or why a central bar forms.

But, you may be saying, supermassive black holes contain millions or billions of Suns' worth of mass. How can such a massive object not be related to the central bar? There are two main reasons: First, the influence of an object's gravity is inversely proportional to the square of the distance you are from that object. This is a complicated way of saying that the gravitational pull you feel from something very quickly becomes weaker as you move away from it. So, given that the bulge of, say, the Milky Way stretches nearly 7,000 light-years across, the sphere of influence around its supermassive black hole is not nearly large enough to dictate the motions of material throughout the entire bulge. The second reason is that the mass of a galaxy's bulge itself — the stars and gas — far outweighs that of its supermassive black hole. The difference is quite extreme: The average supermassive black hole accounts for only about 0.5 percent of the total mass in a galaxy's bulge.

So, despite its location, a supermassive black hole has nothing to do with the formation of a bar structure. Even the acquisition of an additional supermassive black hole from a colliding galaxy could not create a bar — such an event might, in fact, disrupt one. Galactic bars are instead caused by gravitational instabilities in the motion of material in a galaxy's bulge. Because the material throughout a galaxy is not distributed evenly, instabilities arise in areas that start out slightly denser than their surroundings, causing them to attract more material. Given time, the orbits of numerous stars and gas clouds will overlap, creating the structure we see. This is similar to the way spiral arms are generated as density waves cause material in a galaxy's disk to pile up in certain orbits like a traffic jam as the galaxy rotates. And although a bar or spiral arms may look solid, they are really just dense regions where more material is present. Their shape, size, and even existence can change within a single galaxy over its lifetime.

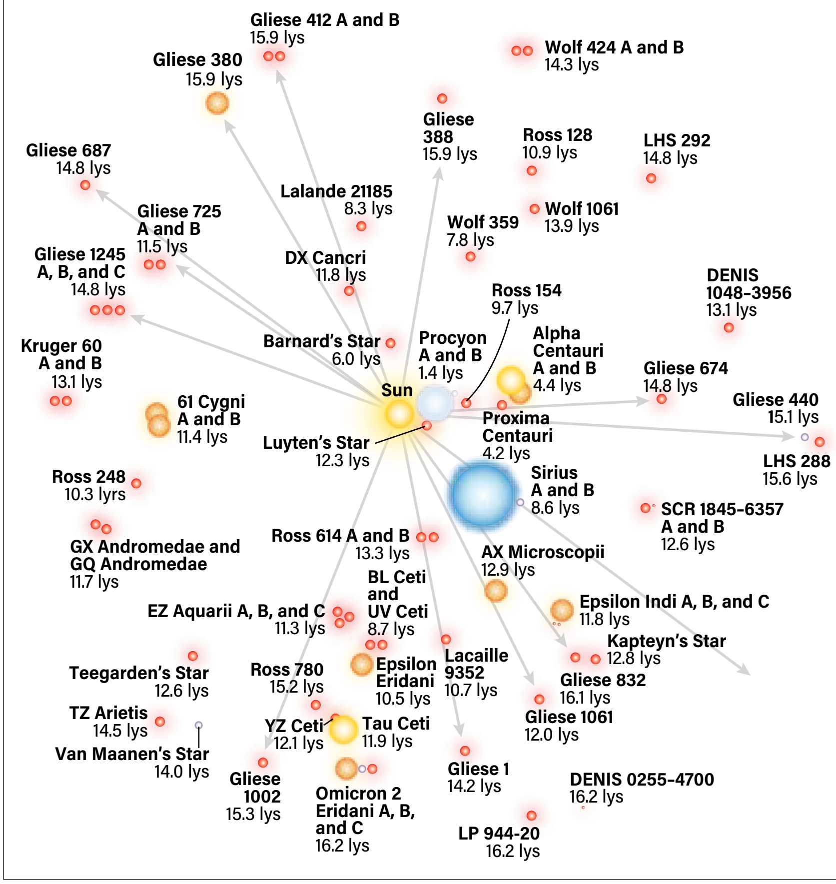
Alison Klesman
Senior Associate Editor

Q | IN YOUR JULY 2020 ISSUE, "STELLAR NEIGHBORS CLOSE-UP" SHOWS MANY STARS WITH THE NAME GLIESE. WHAT OR WHO IS GLIESE?

Patrick Clough
Wichita, Kansas

A | Wilhelm Gliese was a German astronomer who published his *Catalogue of Nearby Stars* in 1957. Today, some stars are still referred to by the number Gliese gave them, such as Gliese 380 and Gliese 710.

CATALOGING OUR STELLAR NEIGHBORS



This simplified diagram from "Stellar neighbors close-up" shows stars out to 16.2 light-years from the Sun. The numbers are their distances in light-years (lys), as measured by the European Space Agency's Hipparcos satellite. The sizes, which come from the Research Consortium on Nearby Stars, are scaled relative to each other, not to the distances between them. Readers may note that several stars bear the name Gliese.
ASTRONOMY: ROEN KELLY

The history of cataloging and naming stars is a long one. Even before written history, civilizations around the world were giving the brightest stars in the night sky unique names. Some names, like Betelgeuse and Sirius, have survived to modern times from their original cultures and are still used today. However, after the advent of the telescope, fainter stars were discovered and the need for a universal cataloging system grew.

The earliest example of such a catalog still in use today is Johann Bayer's 1603 *Uranometria* atlas. In it, Bayer set about labeling the brightest stars in a constellation with the Greek alphabet. His intention was to label the brightest star alpha (α), the second-brightest beta (β), and so on. Unfortunately, his system wasn't always accurate.

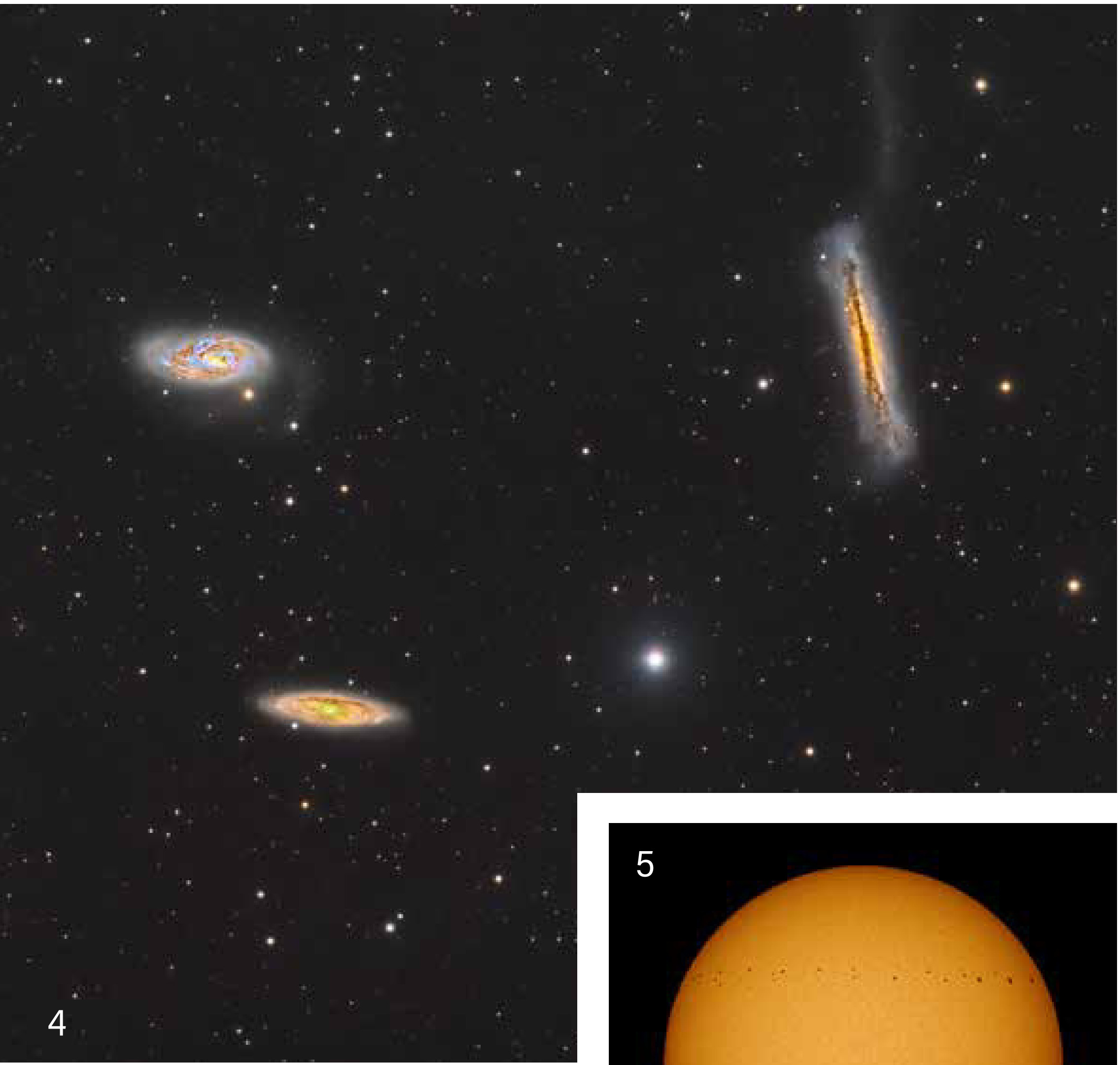
Many other astronomers have attempted to tackle creating an accurate and complete stellar catalog over the centuries. Since 2015, the International Astronomical Union has designated a Working Group on Star Names to formally catalog stellar names. This group has approved many of Gliese's catalog names; hence, some stars carry his name.

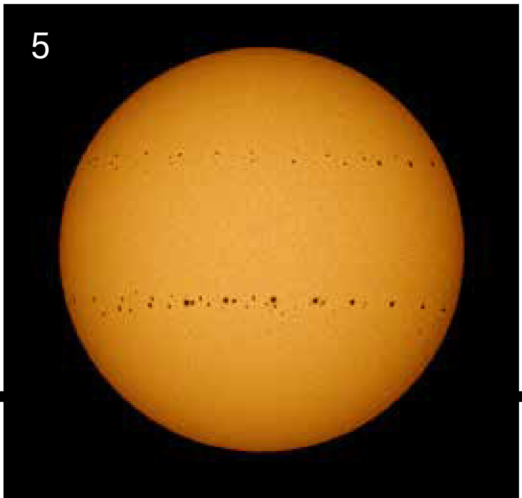
Caitlyn Buongiorno
Associate Editor

Cosmic portraits

1. ETNA ERUPTS
A colorful series of star trails is reflected on Lake Biviere di Cesarò in Sicily, while in the background, Mount Etna erupts on the night of March 12/13, 2021. This incredible combination of fire, water, earth, and sky was captured with a Canon 6D at ISO 3200 and a 20mm f/2 lens in 1,278 15-second exposures.
• Dario Giannobile

2. THE MANE EVENT
Sharpless 2–132, also called the Lion Nebula, shines in this image representing 9.5 hours of exposure with a 5-inch scope. The Hubble palette used to process the image accentuates the dark clouds and Bok globules that dot the glowing gas. It also reveals how many of the nebula's features — like its "tail" on the right — are shock waves formed at the edges of expanding bubbles blown outward by young, hot stars.
• Terry Hancock





3. NOT THE MOON
The Milky Way arcs over the dormant volcanic landscape of Craters of the Moon National Monument in Idaho. On the left, the fuzzy outline of the Andromeda Galaxy (M31) is visible; on the right shine Saturn and Jupiter (brighter). This panorama is made of 77 individual images of 10 seconds each at f/1.4 and ISO 10,000.
• ***Matt Dieterich***

4. LEO'S TRIO
The Leo Triplet is a group of three interacting spiral galaxies: M65 (bottom left), M66 (top left), and NGC 3628 (right). This LRGB image was taken with a 3.25-inch refractor and a total exposure of 21.4 hours. • ***David Wills***

5. GOT SOMETHING ON YOUR FACE, SUN!
This composite image represents 100 consecutive daily shots from late 2020 and the spring of 2021, revealing several groups of sunspots moving across our star's face. The imager, based in Kolkata, India, used a Nikon D5600 and a 600mm zoom lens with a white light solar filter.
• ***Soumyadeep Mukherjee***

SEND YOUR IMAGES TO:
Astronomy Reader Gallery,
P.O. Box 1612, Waukesha, WI 53187.
Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**

BEAUTY ON THE BRINK

When you're looking for a dramatic way to celebrate the Hubble Space Telescope's 31st anniversary, it's hard to go wrong with the brilliant star AG Carinae and the dazzling nebula that encircles it. AG Car is a luminous blue variable, a brief stage in the waning days of a short-lived massive star. This colossus holds roughly 70 times the Sun's mass and shines 1 million times brighter than our star. The surrounding nebula spans 5 light-years and contains about 10 solar masses of material jettisoned by the star some 10,000 years ago. AG Car's fierce stellar wind, which blows at more than 600,000 mph (1 million km/h), has since swept up this star stuff. The reddish glow comes from ionized hydrogen laced with nitrogen, while the bluish structures are dust clumps reflecting the star's light. NASA/ESA/STSCI

A NEW STANDARD
OF EXCELLENCE
STELLARVUE®
WWW.STELLARVUE.COM
11802 KEMPER RD
AUBURN, CA 95603
(530) 823-7796
STELLARVUE
STELLARVUE SVX152T
Premier APO Triplet
* * *
Optics are figured, tested, and
assembled in the USA!
Shown with an optional Software Bisque MyT mount, Stellarvue K2 Tripod, Stellarvue Quartz Diagonal, and Optimus Eyepiece.
Milky Way Image by Tony Hallas